Using Program Test Result Data to Evaluate the Phoenix I/M Program

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Executive Summary

This report uses emissions test result data from 1997 to evaluate the effectiveness of the enhanced I/M program in reducing vehicle tailpipe emissions in Phoenix, Arizona. The analysis is based on a comparison of initial and final test results for individual vehicles that received their initial I/M test in 1997. Two types of tests are performed on vehicles subject to I/M testing in Phoenix; the idle and loaded idle test is required of 1980 and older vehicles, while 1981 and newer vehicles must take the IM240 test. Significant differences between the two types of test require that the emissions of the two fleets be analyzed separately.

Arizona allows vehicles to fast pass or fast fail the IM240 test; in order to compare emissions of vehicles tested over different portions of the IM240, we must convert these "short test" results to full IM240 test equivalents. A relatively simple method to make this conversion is used; a comparison of this method with other more detailed methods indicates that all methods tend to underestimate full IM240 emissions using fast pass/fast fail emissions results. The analysis does not consider the effect of the I/M program on reducing evaporative HC emissions.

Comparison of initial and final IM240 tests indicates that the program is reducing the average per vehicle emissions by 16% for HC, 17% for CO, and 7% for NOx, for the entire vehicle fleet. After weighting per vehicle emissions by estimated annual miles traveled, the fleetwide emissions reductions are 2.3 tons per day (14% reduction) for HC, 34 tons per day (15% reduction for CO), and 2.3 tons per day (7% reduction) for NOx. CO and NOx reductions appear to be substantially larger for cars than for light duty trucks. Per vehicle emissions of the loaded idle fleet are reduced by 15% for HC and 23% for CO.

About 11% of all vehicles fail their initial IM240 emissions test; the failure rate is slightly higher for passenger cars (12%) than for light duty trucks (8%). The initial failure rate for the loaded idle test is 37%. Of the vehicles that fail their initial test, only 70% received a final passing test through March 1998; 30% did not receive a final passing test through March 1998. Because waivered vehicles are not identified in the data, the actual percentage of No Final Pass vehicles is likely to be closer to 26%. The percentage of No Final Pass cars is greater than the percentage of No Final Pass trucks.

The percent reductions in loaded idle emissions for Final Pass vehicles tend to increase by model year, with larger reductions for newer vehicles. There is a large increase in percent reduction for model year 1974 through 1980 vehicles, presumably due to stricter cutpoints applied to those vehicles. The percentage reductions of IM240 Final Pass vehicles from model years 1981 through 1993 are fairly constant by model year. HC and CO emission reduction percentages tend to increase after model year 1993.

We use a relatively crude method to estimate total emissions and emission reductions in tons per day for the loaded idle fleet, in order to estimate the tonnage reductions for the entire Phoenix I/M program. We estimate that the program reduces the emissions of the fleet reporting for I/M by 3.0 tons per day for HC, 38 tons per day for CO, and 2.6 tons per day for NOx. The majority of the estimated emissions reductions comes from the IM240 fleet: 76% for HC, and 88% for CO

and NOx. The estimated percent reduction in total emssions is 15% for HC, 13% for CO, and 7% for NOx.

The estimated effectiveness of the I/M program depends on whether the No Final Pass vehicles have been permanently removed from the I/M area, or if they continue to be driven in the I/M area. The effectiveness of the program on the IM240 fleet nearly doubles if one assumes that all IM240 No Final Pass vehicles have been permanently removed from the area. Analysis of 1995 IM240 test data and remote sensing data indicate that about half of the No Final Pass vehicles continue to be driven in the I/M area. If this information is correct for vehicles tested in 1997, the 1997 I/M program resulted in a 22% reduction in HC and CO, and a 9% reduction in NOx from the IM240 fleet. These percentage reductions are equivalent to 3.0 tons per day for HC and NOx, and 48 tons per day for CO.

Analysis of a single year of I/M program test data can only provide a partial understanding of the program's effectiveness in reducing emissions. Tracking of individual vehicles over several I/M cycles can reveal important information on long-term effectiveness of vehicle repair, and changes in the fleet reporting for I/M testing. In addition, an independent source of on-road emissions tests, such as from a remote sensing measurement program, can provide additional information on repair effectiveness, the effect of pre-test repairs on emissions, and the number and emissions of vehicles avoiding the I/M program.

1. Introduction

This report uses emissions test result data from 1997 to evaluate the effectiveness of the enhanced I/M program in reducing vehicle tailpipe emissions in Phoenix, Arizona. Effectiveness is measured in terms of both percent and absolute tons of emissions reduced. The analysis is based on a comparison of initial and final test results for individual vehicles, on either the IM240 or the loaded idle test, depending on the age of the vehicle.

Model year 1981 and newer vehicles with two-wheel drive are subject to IM240 dynamometer testing in the Phoenix I/M program. Model year 1967 to 1980 vehicles registered in the Phoenix area are subject to an idle and a loaded idle I/M test. Both idle test emissions are reported as pollutant concentrations in the exhaust (percent for CO, parts per million for HC), which are not directly comparable to the mass emissions (grams per mile) reported from IM240 tests. In addition, NOx emissions are not measured under the idle tests. Because of these differences between the two tests, we analyze the fleet of vehicles subject to each type of test separately. For the pre-1981 vehicles we use emissions from the loaded idle test, since this test is somewhat more similar to the IM240 test than the conventional idle test. Because they cannot be driven on the dynamometers used for IM240 or loaded idle testing, all-wheel drive vehicles of all model years are subject to an idle test only. 13,000 such vehicles registered in the Phoenix area were tested in 1997; nearly 90% of these vehicles are 1981 and newer. We exclude all of these all-wheel drive vehicles from our analysis.

There is another important difference between the test results for loaded idle and IM240 tests. Vehicles subject to the IM240 test are classified as either passenger cars, light duty trucks less than 6,000 pounds, or light duty trucks between 6,000 pounds and 8,500 pounds. However, vehicles subject to loaded idle testing are classified as either: 1) less than 6,000 pounds and 4 or fewer cylinders; 2) less than 6,000 pounds and more than 4 cylinders; or 3) between 6,000 pounds and 8,500 pounds. Therefore, comparison of the IM240 and loaded idle fleets by vehicle type requires that the first two classifications (passenger cars and light duty trucks under 6,000 pounds) be merged into a single group.

The next section describes the process used to convert IM240 short test emission results to full IM240 equivalent emissions levels. Section 3 presents estimates of program effectiveness by vehicle type/class, for each of the IM240 and loaded idle vehicle fleets; Section 4 presents program effectiveness for each fleet by I/M test result. In Section 5 we combine the data from the analysis of the two independent fleets to derive estimates of program effectiveness on all vehicles reporting for I/M testing. Section 6 discusses how vehicles that never complete I/M testing affect the evaluation of program effectiveness. Other issues critical to accurate evaluation of I/M programs, but not specifically addressed here, are discussed in Section 7. Section 8 summarizes our results and provides some conclusions.

2. IM240 Short Test Conversion

This analysis is based on all initial IM240 tests of vehicles performed in 1997, with the exceptions described below. Arizona allows vehicles to either “fast pass” the IM240 after only 31 seconds of testing, or “fast fail” the test after 94 seconds of testing. Therefore, virtually all vehicles are either passed or failed before they complete the full 240 seconds of the IM240 test. To compare emissions of vehicles tested over different portions of the IM240, we must convert these "short test" results to full IM240 test equivalents.

We used a rather simple method to make this conversion; we obtained from EPA second-by-second full IM240 test results on 4,000 vehicles conducted by Automotive Testing Laboratories (ATL) in Arizona in 1992. Figure 1 shows the speed time trace of the IM240 (right scale), and the average gram per mile emissions of the ATL test fleet at each second of the test (left scale). For each second of the test, cumulative grams are divided by cumulative miles for each vehicle, and the results are averaged over the fleet. The highest average gram per mile values occur at second 30, and decrease as the test continues. The hardest acceleration in the IM240 occurs just before second 160; this acceleration causes the cumulative average gram per mile values for CO and NOx to increase slightly.

We then calculated the ratio of the emissions at each second to the emissions for the full IM240, for each pollutant for each vehicle. Figure 2 shows the ratios averaged over all vehicles, for each pollutant; we use these average ratios as adjustment factors to convert short test results to full test equivalent emissions. The adjustment factors are quite large for vehicles passed immediately after 30 seconds; for example, for these vehicles we divided measured HC gram per mile values by 3.4 to obtain full-IM240 equivalent HC emissions. Each of the adjustment factor curves reaches 1 at second 240, indicating that no adjustments were made to vehicles driven the full 240 seconds of the test.

Figure 1. Average gpm Emissions at Each Second of IM240
ATL Arizona Data

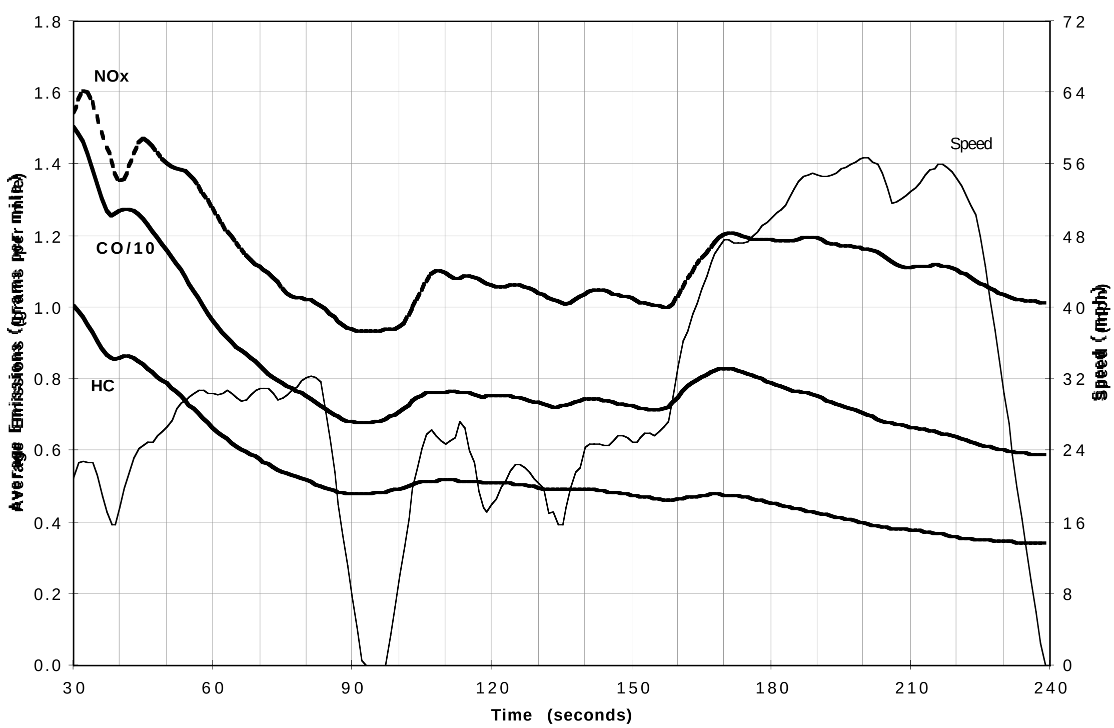
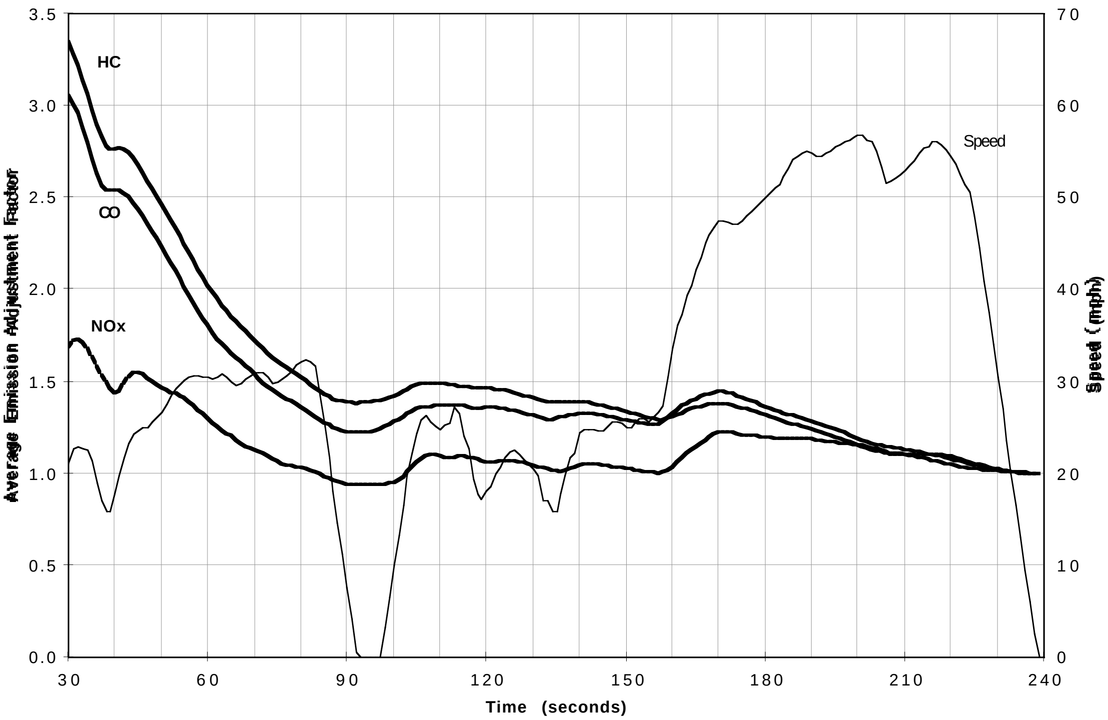


Figure 2. Average Emission Adjustment Factor for Each Second,
ATL Arizona Data



Our method involves dividing measured emissions at a given second by a conversion factor, based only on the second of testing. Others have developed different, more involved methods for converting short test emissions, using other variables such as vehicle type and age. We have compared several different methods for converting short test emissions to full IM240 equivalents (the comparison is included as Appendix A of this report). This comparison found that all of the methods tend to underestimate full IM240 emissions of fast pass vehicles. One reason for the underestimation is that a small number of vehicles (one or two percent) are improperly fast passed; if allowed to complete the full IM240 test, their emissions would exceed the full IM240 cutpoints. In general, all of the conversion methods are more accurate for vehicles tested over longer segments of the IM240 test. Since Arizona does not fail high emitters until at least second 94 of the IM240, we believe the adjustment is more accurate for the failing vehicles than vehicles passed immediately after second 30.

3. Initial Program Effectiveness by Vehicle Type/Class

To estimate initial effectiveness of the Phoenix program, we compared the initial and last test of each vehicle with an initial test in 1997. To do this we first matched all vehicle tests by vehicle identification number (VIN). For vehicles with subsequent retests, we took the last retest through March 1998 as the final test of the vehicle. For vehicles that passed their initial test, and vehicles that failed their initial test but did not receive a retest, we assumed that their emissions were equivalent to those measured during their initial test. We excluded from our analysis 4,000

IM240 tests with invalid VINs[1] (less than 1% of all tests) and 18,000 vehicles (or 2.5% of all unique vehicles) with subsequent tests coded as initial tests[2,3]. Excluding these vehicles from our analysis has little effect on average emissions per vehicle, but has a larger effect on absolute tons of emissions.

Table 1 shows the average initial and final emissions, in adjusted grams per mile, of passenger cars, light duty trucks less than 6,000 pounds GVW (LDT1), and light duty trucks between 6,000 and 8,500 pounds GVW (LDT2) tested on the IM240 in 1997. Table 2 shows the same data for the vehicles subject to the idle test. The table also shows the percentage emissions reduction for each vehicle type, and for the fleet as a whole, as measured by comparing the initial test with the final test of each vehicle. The tables indicates that the Phoenix I/M program is reducing emissions of the IM240 fleet by 16% for HC, 17% for CO, and 7% for NOx; the loaded idle emissions of the idle fleet are reduced by 15% for HC and 23% for CO.[4] The percentage reduction in IM240 CO and NOx, and the percentage reduction in loaded idle CO, appear to be substantially larger for cars than for light duty trucks. (This analysis does not consider evaporative HC emissions, and therefore understates the program's effectiveness in reducing total HC).

Table 1. Average Emissions and Percent Reduction, IM240 Fleet, Unweighted by Annual VMT

		Unweighted Average Emissions per Vehicle (adjusted grams per mile)						Percent Reduction		
		HC		CO		NOx				
Type	Number	Initial	Final	Initial	Final	Initial	Final	HC	CO	NOx
Cars	431,098	0.62	0.52	8.98	7.23	1.26	1.15	16.6%	19.5%	8.6%
LDT1	185,888	0.85	0.73	11.97	10.41	1.62	1.52	14.2%	13.0%	6.1%
LDT2	53,789	1.06	0.88	14.50	12.44	2.18	2.08	16.8%	14.2%	4.5%
All	670,775	0.72	0.61	10.25	8.53	1.43	1.33	15.8%	16.8%	7.3%

1. The VIN has a check digit that can be used to determine if the combination of numerals and characters in the VIN are valid. Less than one percent of the vehicles had an invalid VIN.
2. There are several reasons why a vehicle may have multiple initial tests within a two-year period: vehicles for sale by dealers that are not fleet-licensed must be tested every 90 days; subsequent tests of vehicles that were not passed within 5 months of the initial test are coded as initial tests; some repeat initial tests are for research purposes only; a small number of audit vehicles are covertly run through the system periodically; and a prospective buyer may voluntarily test a vehicle prior to purchase (personal communication with Frank Cox, Arizona Department of Environmental Quality).
3. We did not exclude any loaded idle tests because of invalid VINs, because the VIN was not standardized across all vehicle manufacturers until the 1981 model year. We did exclude 40,000 vehicles subject to the loaded idle test with multiple initial tests.
4. Idle emissions of the idle fleet are reduced by 25% for HC and 30% for CO.

Table 2. Average Emissions and Percent Reduction, Loaded Idle Fleet, Unweighted by Annual VMT

Type	Number	Unweighted Average Emissions per Vehicle (emissions concentration)					
		HC (ppm)		CO (%)		Percent Reduction	
		Initial	Final	Initial	Final	HC	CO
Class 3	15,774	145	121	1.53	1.13	16.1%	26.0%
Class 4	66,573	113	95	1.17	0.90	15.6%	23.0%
Class 5	23,653	113	97	1.28	1.03	14.1%	19.5%
All	106,000	118	100	1.25	0.96	15.4%	22.7%

Tables 1 and 2 show the average emissions per vehicle; however, for inventory purposes, the per vehicle emissions reductions have to be weighted by the average number of annual miles driven by different types and ages of vehicles. Table 3 shows the average IM240 emissions from Table 1 in terms of tons per day, using EPA's latest estimates of annual vehicle miles traveled (VMT) by vehicle type and age (Acurex, 1997). Table 3 indicates slightly lower emissions reductions than Table 1. The absolute tons per day values in Table 3 may not be directly comparable to estimates of the Arizona mobile source emissions inventory, since the method to adjust the emissions of fast pass vehicles tends to underestimate full IM240 emissions of the majority of vehicles, as described above. In addition, vehicles with invalid VINs and with multiple initial tests have been excluded, as described above. Again, percentage CO and NOx reductions appear to be substantially larger for cars than for light duty trucks.

Table 3. Total Emissions and Percent Reduction, Weighted by Annual VMT

Type	Number	Total Emissions (Tons per Day)						Percent Reduction		
		HC		CO		NOx				
		Initial	Final	Initial	Final	Initial	Final	HC	CO	NOx
Cars	431,096	8.7	7.4	125.7	103.1	18.8	17.3	15.3%	18.0%	7.6%
LDT1	185,885	5.1	4.4	72.9	64.8	10.6	9.9	13.0%	11.2%	6.0%
LDT2	53,788	2.0	1.7	26.9	23.7	4.8	4.6	14.3%	11.9%	3.7%
All	670,769	15.8	13.5	225.6	191.7	34.1	31.9	14.4%	15.0%	6.6%
Reduction			*2.3*		*34.0*		*2.3*			

Note: Absolute tons of emissions may not be comparable to official emissions inventories, due to conversion of fast pass/fast fail emissions to full IM240 emissions and exclusion of vehicles with invalid VINs, multiple initial tests, or that do not report for I/M testing.

As discussed above, we cannot calculate tons per day of the vehicles subject to the loaded idle test. In addition, we cannot calculate average idle emissions weighted by annual vehicle miles traveled, as the VMT assumptions we use vary by vehicle type as well as model year, and the loaded idle data are not classified by the same vehicle types. We return to this issue in Section 6.

4. Initial Program Effectiveness by I/M Result

As discussed above, we determined the final I/M result of each vehicle initially tested in 1997. We grouped vehicles into four groups, based on their first and last emissions test[5]:

1) vehicles that passed their initial test ("Initial Pass");
2) vehicles that failed their initial test, but passed a subsequent retest ("Final Pass")[6];
3) vehicles that failed their initial test and failed a subsequent retest ("No Final Pass"); and
4) vehicles that failed their initial test and had no retest ("No Second Test").

We frequently treat groups 3 and 4 as a single group, No Final Pass vehicles.

Tables 4 and 5 show the number and distribution of vehicles by vehicle type/class and I/M result. No Final Pass and No Second Test vehicles are shown separately, and grouped together and shown in italics. Table 4 indicates that about 11% of all vehicles fail their initial IM240 emissions test; the failure rate is slightly higher for passenger cars (12%) than for light duty trucks (8%). Table 5 shows that nearly three times as many vehicles fail their initial idle or loaded idle test (37%); again, the idle failure rate is higher for Class 5 vehicles (LDT2; 36%) than Class 3 vehicles (cars and LDT1 with 4 or fewer cylinders; 44%). Of the vehicles that fail their initial IM240 test, only 70% received a final passing test in 1997; 30% did not receive a final passing test in 1997. The percentage of IM240 No Final Pass cars is greater than the percentage of No Final Pass trucks (33% for cars, 23% for LDT1, 21% for LDT2). The overall No Final Pass rate for vehicles subject to loaded idle testing is similar to that for IM240 vehicles, with the No Final Pass rate decreasing as the class increases (38% for Class 3, 28% for Class 4, and 24% for Class5).

5. About 4% of all IM240 vehicles, and 20% of all loaded idle vehicles, passed their initial emissions test but failed either a functional or visual test; these vehicles are excluded from our analysis by I/M result.
6. Presumably emissions controls malfunctions are identified and repaired for most of these vehicles; however, it is possible that a number of these vehicles pass a retest without any permanent repairs being made.

Table 4. Number of IM240 Vehicles by Type and I/M Result*

Type	I/M Result	Number	Percent of Total	Percent of Initial Fails
Cars	1) Initial Pass	365,983	87.8%	
	2) Final Pass	33,912	8.1%	66.7%
	3) No Final Pass	9,348	2.2%	18.4%
	4) No Second Test	7,575	1.8%	14.9%
	Subtotal 3 and 4	*16,923*	*4.1%*	*33.3%*
	All Cars	416,818	100.0%	100.0%
LDT1	1) Initial Pass	161,450	91.8%	
	2) Final Pass	11,112	6.3%	77.2%
	3) No Final Pass	1,829	1.0%	12.7%
	4) No Second Test	1,448	0.8%	10.1%
	Subtotal 3 and 4	*3,277*	*1.9%*	*22.8%*
	All LDT1	175,839	100.0%	100.0%
LDT2	1) Initial Pass	45,694	91.6%	
	2) Final Pass	3,283	6.6%	78.8%
	3) No Final Pass	446	0.9%	10.7%
	4) No Second Test	438	0.9%	10.5%
	Subtotal 3 and 4	*884*	*1.8%*	*21.2%*
	All LDT2	49,861	100.0%	100.0%
All Vehicles	1) Initial Pass	573,127	89.2%	
	2) Final Pass	48,307	7.5%	69.6%
	3) No Final Pass	11,623	1.8%	16.8%
	4) No Second Test	9,461	1.5%	13.6%
	Subtotal 3 and 4	*21,084*	*3.3%*	*30.4%*
	Total	642,518	100.0%	100.0%

*Excludes 4% of vehicles that pass initial emissions test but fail initial visual or functional test.

Table 5. Number of Loaded Idle Vehicles by Class and I/M Result*

Class	I/M Result	Number	Percent of Total	Percent of Initial Fails
Class 3	1) Initial Pass	8286	55.5%	
(Cars and	2) Final Pass	4122	27.6%	61.9%
LDT1 with 4	3) No Final Pass	1465	9.8%	22.0%
or fewer	4) No Second Test	1069	7.2%	16.1%
cylinders)	*Subtotal 3 and 4*	*2,534*	*17.0%*	*38.1%*
	All Class 3	14,942	100.0%	100.0%
Class 4	1) Initial Pass	39579	64.7%	
(Cars and	2) Final Pass	15508	25.3%	71.8%
LDT1 with	3) No Final Pass	3405	5.6%	15.8%
more than 4	4) No Second Test	2699	4.4%	12.5%
cylinders	*Subtotal 3 and 4*	*6,104*	*10.0%*	*28.2%*
	All Class 4	61,191	100.0%	100.0%
Class 5	1) Initial Pass	13668	63.9%	
(LDT2)	2) Final Pass	5889	27.5%	76.2%
	3) No Final Pass	1005	4.7%	13.0%
	4) No Second Test	839	3.9%	10.8%
	Subtotal 3 and 4	*1,844*	*8.6%*	*23.8%*
	All Class 5	21,401	100.0%	100.0%
All Vehicles	1) Initial Pass	61,533	63.1%	
	2) Final Pass	25,519	26.2%	70.9%
	3) No Final Pass	5,875	6.0%	16.3%
	4) No Second Test	4,607	4.7%	12.8%
	Subtotal 3 and 4	*10,482*	*10.7%*	*29.1%*
	Total	97,534	100.0%	100.0%

*Excludes 20% of vehicles that pass initial emissions test but fail initial visual or functional test.

The database we use for our analysis does not identify vehicles that exceed the cost repair limit without passing the test, and receive a waiver. Arizona DEQ reports that the waiver rate is about 4% of all vehicles that fail their initial test. If we assume that all of these waivered vehicles are classified as No Final Pass vehicles in our classification scheme, then the percentage of 1997 initial fail vehicles that never complete I/M testing is reduced to about 26%.

Another possibility for the high number of No Final Pass vehicles is that the VIN of a passing retest of these vehicles was entered incorrectly into the database, and therefore the passing retest was not matched with the initial test. To test this we sorted all tests of No Final Pass (including No Second Test) IM240 vehicles by vehicle license plate rather than VIN; it would be very unlikely for both the VIN and license plate to be incorrectly entered for the same vehicle. We found that only three of these vehicles had a subsequent retest with an invalid VIN; each of these vehicles failed the retest (one vehicle had two retests with invalid VINs, and failed both).

Tables 6 and 7 show the average initial and final emissions by I/M result, by vehicle type/class and for all vehicles. As noted above, we assume that the "final" emissions of vehicles with no second test, the Initial Pass and No Second Test vehicles, are the same as their initial emissions. IM240 emissions of the Final Pass vehicles are dramatically reduced by the I/M program: HC and CO emissions of these vehicles are reduced by over 60%, while NOx emissions are reduced by 45%. The percent reduction of CO and NOx emissions is somewhat greater for cars than light duty trucks. Presumably, much of this reduction is due to actual repairs made to vehicles; however, it is possible that initially failing vehicles can pass a retest without any repairs having been made. In addition, the emissions of No Final Pass vehicles also are reduced somewhat, presumably from partial repairs made to some vehicles in this group.

Table 6. Average IM240 Emissions and Percent Reduction by Vehicle Type and I/M Result, Unweighted by Annual VMT*

		Unweighted Average Emissions per Vehicle (adjusted grams per mile)						Percent Reduction		
		HC		CO		NOx				
Type	I/M Result	Initial	Final	Initial	Final	Initial	Final	HC	CO	NOx
Cars	1) Initial Pass	0.39	0.39	5.36	5.36	1.05	1.05	0.0%	0.0%	0.0%
	2) Final Pass	2.01	0.75	30.89	9.45	2.81	1.48	62.4%	69.4%	47.5%
	3) No Final Pass	2.95	2.71	43.59	39.69	2.63	2.48	8.1%	8.9%	5.9%
	4) No Second Test	3.04	3.04	46.46	46.46	2.55	2.55	0.0%	0.0%	0.0%
	Subtotal 3 and 4	*3.00*	*2.88*	*45.08*	*43.14*	*2.59*	*2.51*	*3.9%*	*4.3%*	*2.9%*
	All Cars	0.62	0.52	9.04	7.21	1.26	1.15	17.2%	20.3%	8.9%
LDT1	1) Initial Pass	0.60	0.60	8.83	8.83	1.41	1.41	0.0%	0.0%	0.0%
	2) Final Pass	3.21	1.22	43.12	16.61	3.68	2.09	62.2%	61.5%	43.1%
	3) No Final Pass	4.46	4.13	55.99	53.48	3.30	3.14	7.3%	4.5%	5.0%
	4) No Second Test	4.48	4.48	58.23	58.23	3.34	3.34	0.0%	0.0%	0.0%
	Subtotal 3 and 4	*4.47*	*4.28*	*56.98*	*55.58*	*3.32*	*3.23*	*4.0%*	*2.5%*	*2.8%*
	All LDT1	0.84	0.71	11.90	10.20	1.59	1.49	15.4%	14.3%	6.4%
LDT2	1) Initial Pass	0.72	0.72	10.26	10.26	2.02	2.02	0.0%	0.0%	0.0%
	2) Final Pass	4.26	1.45	55.77	21.77	3.81	2.37	66.0%	61.0%	37.8%
	3) No Final Pass	5.58	4.97	70.69	64.70	3.27	3.05	11.0%	8.5%	6.8%
	4) No Second Test	5.66	5.66	75.02	75.02	3.25	3.25	0.0%	0.0%	0.0%
	Subtotal 3 and 4	*5.62*	*5.31*	*72.83*	*69.81*	*3.26*	*3.15*	*5.5%*	*4.2%*	*3.5%*
	All LDT2	1.04	0.85	14.37	12.08	2.16	2.06	18.2%	16.0%	4.5%
All	1) Initial Pass	0.47	0.47	6.73	6.73	1.23	1.23	0.0%	0.0%	0.0%
	2) Final Pass	2.44	0.91	35.39	11.93	3.08	1.68	62.8%	66.3%	45.5%
	3) No Final Pass	3.29	3.02	46.58	42.82	2.76	2.60	8.1%	8.1%	5.8%
	4) No Second Test	3.38	3.38	49.58	49.58	2.70	2.70	0.0%	0.0%	0.0%
	Subtotal 3 and 4	*3.34*	*3.20*	*48.09*	*46.19*	*2.73*	*2.65*	*4.1%*	*4.0%*	*2.9%*
	Total	0.72	0.60	10.23	8.40	1.42	1.31	16.7%	17.9%	7.6%

*Excludes 4% of vehicles that pass initial emissions test but fail initial visual or functional test.

Table 7 shows that the CO emission reduction percentage of the loaded idle fleet (24%) is greater than the HC reduction (16%), and is greater than the CO reduction of the IM240 fleet (18%, Table 6). Emission reductions of Final Pass vehicles in the loaded idle fleet tend to be smaller than the percentage reductions of their counterparts in the IM240 fleet; however, because there are so many more Final Pass vehicles in the loaded idle fleet (Table 5 vs. Table 4), the result is larger overall emissions reductions across all vehicles.[7]

7. Idle emission reductions, both for the Final Pass vehicles and the overall fleet, are substantially higher than loaded idle emissions reductions. For instance, fleet idle emissions are reduced 26% for HC and 31% for CO.

Table 7. Average Loaded Idle Emissions and Percent Reduction by Vehicle Type and I/M Result, Unweighted by Annual VMT*

Type	I/M Result	Unweighted Average Emissions (ppm/%) per Vehicle				Percent Reduction	
		HC (ppm)		CO (%)			
		Initial	Final	Initial	Final	HC	CO
Class 3 (Cars and LDT1 with 4 or fewer cylinders)	1) Initial Pass	96	96	0.81	0.81	0.0%	0.0%
	2) Final Pass	190	104	2.41	0.90	45.1%	62.7%
	3) No Final Pass	243	232	2.76	2.67	4.4%	3.3%
	4) No Second Test	267	267	2.91	2.91	0.0%	0.0%
	Subtotal 3 and 4	*253*	*247*	*2.82*	*2.77*	*2.5%*	*1.8%*
	All Class 3	149	124	1.59	1.16	16.6%	26.7%
Class 4 (Cars and LDT1 with more than 4 cylinders	1) Initial Pass	85	85	0.77	0.77	0.0%	0.0%
	2) Final Pass	164	92	2.00	0.85	44.3%	57.5%
	3) No Final Pass	209	195	2.47	2.37	6.7%	4.1%
	4) No Second Test	210	210	2.26	2.26	0.0%	0.0%
	Subtotal 3 and 4	*209*	*202*	*2.38*	*2.33*	*3.7%*	*2.3%*
	All Class 4	117	98	1.24	0.95	16.4%	23.9%
Class 5 (LDT2)	1) Initial Pass	87	87	0.90	0.90	0.0%	0.0%
	2) Final Pass	155	94	2.03	1.04	39.2%	48.8%
	3) No Final Pass	210	194	2.35	2.24	7.4%	4.7%
	4) No Second Test	204	204	2.20	2.20	0.0%	0.0%
	Subtotal 3 and 4	*207*	*199*	*2.28*	*2.22*	*4.1%*	*2.6%*
	All Class 5	116	99	1.33	1.05	15.0%	20.9%
All	1) Initial Pass	87	87	0.81	0.81	0.0%	0.0%
	2) Final Pass	166	94	2.07	0.90	43.3%	56.5%
	3) No Final Pass	217	204	2.53	2.43	6.2%	3.9%
	4) No Second Test	222	222	2.40	2.40	0.0%	0.0%
	Subtotal 3 and 4	*219*	*212*	*2.47*	*2.42*	*3.4%*	*2.3%*
	Total	122	102	1.32	1.00	16.1%	23.7%

*Excludes 20% of vehicles that pass initial emissions test but fail initial visual or functional test.

Some of the differences in average emissions by I/M result is attributable to different vehicle age distributions in each of the vehicle groups. For instance, more newer vehicles are in the Initial Pass group, while more older vehicles are in the Final Pass or No Final Pass groups. Figures 3 through 5 present the average passenger car emissions by I/M result and model year for the IM240 fleet; Figures 6 and 7 present the same data for Class 4 vehicles of the loaded idle fleet. The initial emissions of the Initial Pass cars are compared with the initial and final emissions of the Final Pass and the No Final Pass (including No Second Test) groups.

The figures demonstrate that, for the most part, both initial and final HC and CO emissions are lower for newer vehicles than for older vehicles. This trend is due to a combination of better emissions control technology on newer vehicles, less aging and mileage accumulation of newer vehicles, and more stringent cutpoints for newer vehicles. (For example, the sharp decrease in HC emissions between model year 1990 and 1991 cars, most notable in for Final Pass and No Final Pass vehicles, is likely due to more stringent IM240 cutpoints applied to model year 1991 and newer vehicles.) Initial NOx emissions are fairly steady for 1990 and older cars; however,

Figure 3. Average HC by MY and I/M Result

Passenger Cars, 1997 Arizona IM240

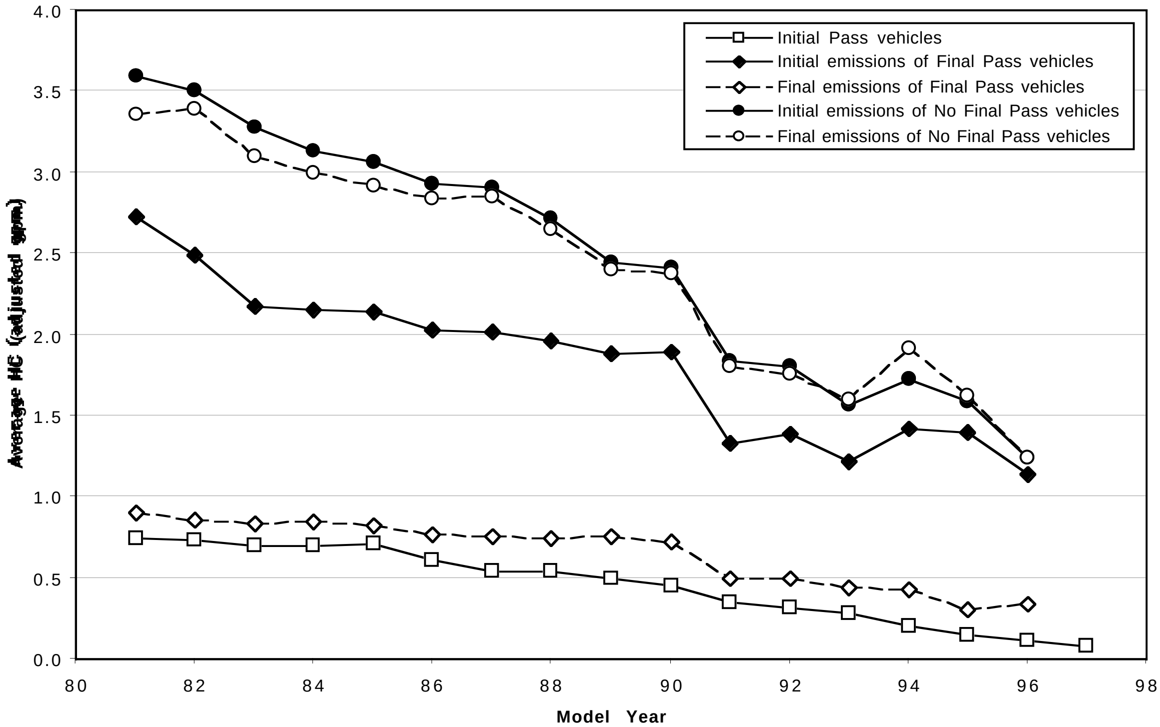


Figure 4. Average CO by MY and I/M Result

Passenger Cars, 1997 Arizona IM240

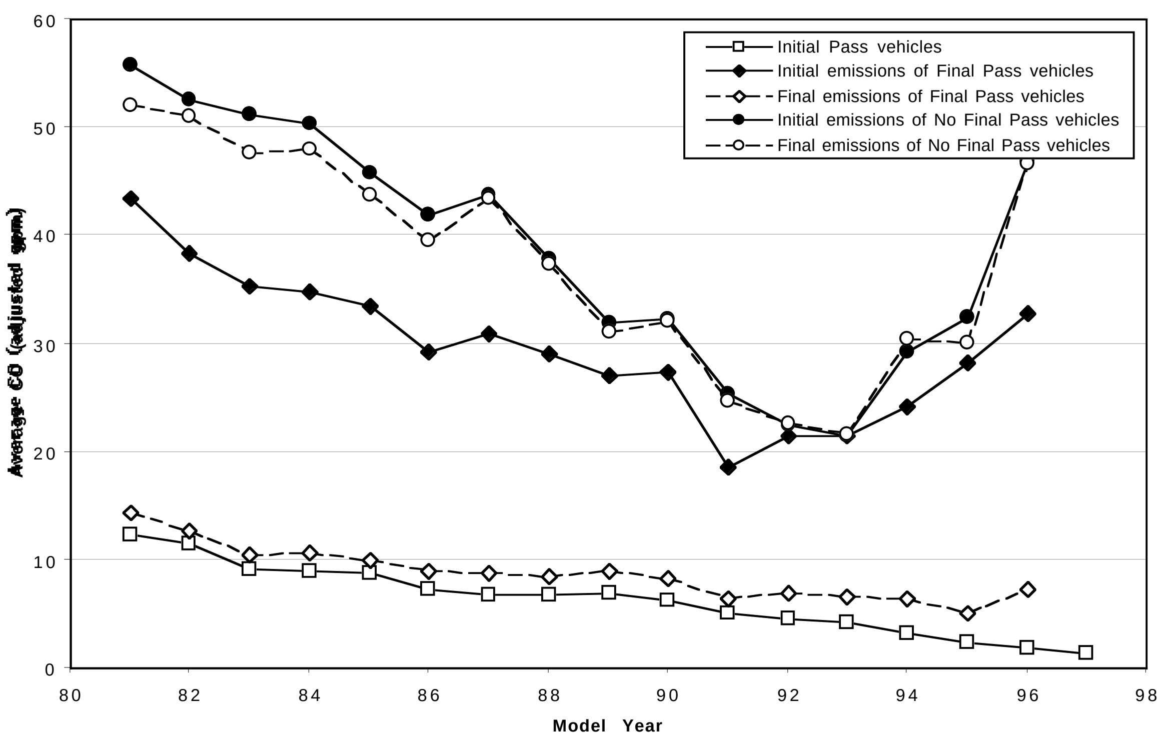


Figure 5. Average NOx by MY and I/M Result

Passenger Cars, 1997 Arizona IM240

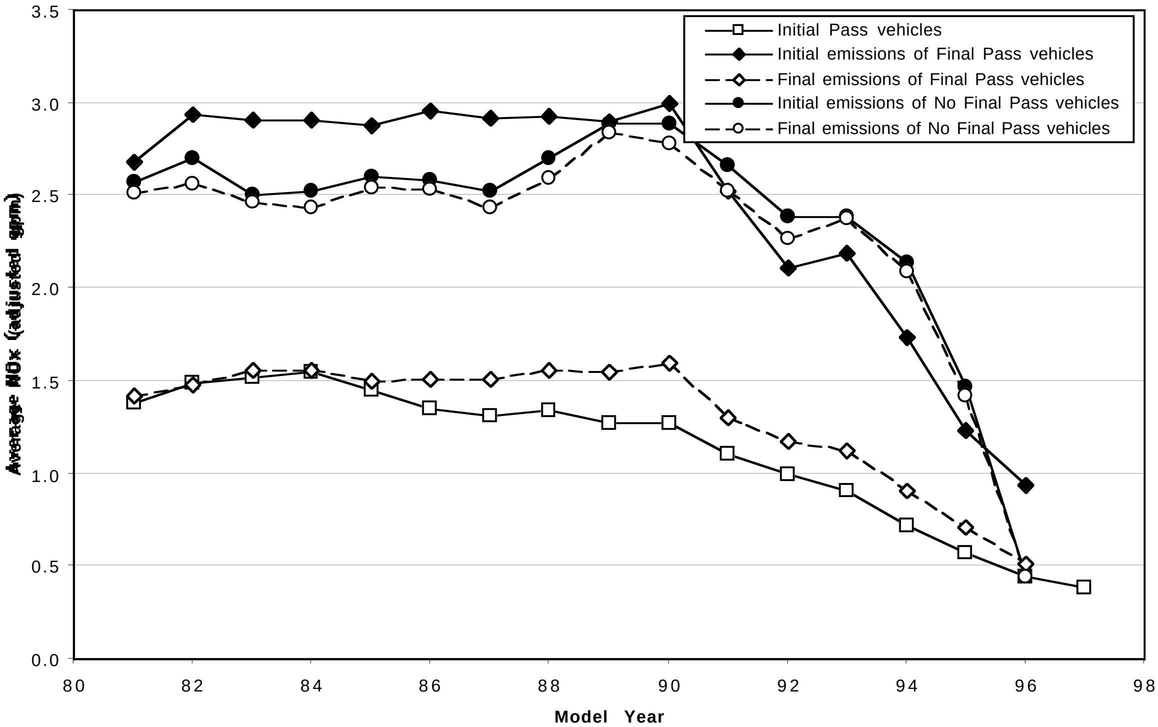


Figure 6. Average Loaded Idle HC by MY and I/M Result

Class 4 Vehicles, 1997 Arizona Idle

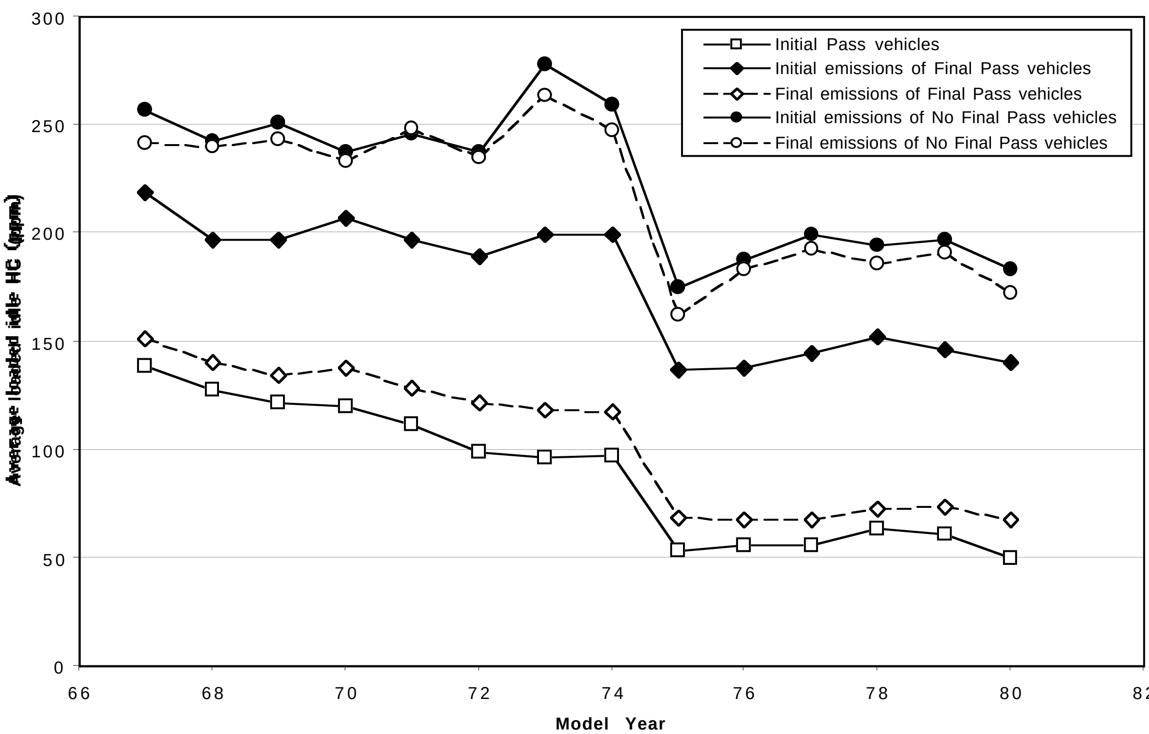
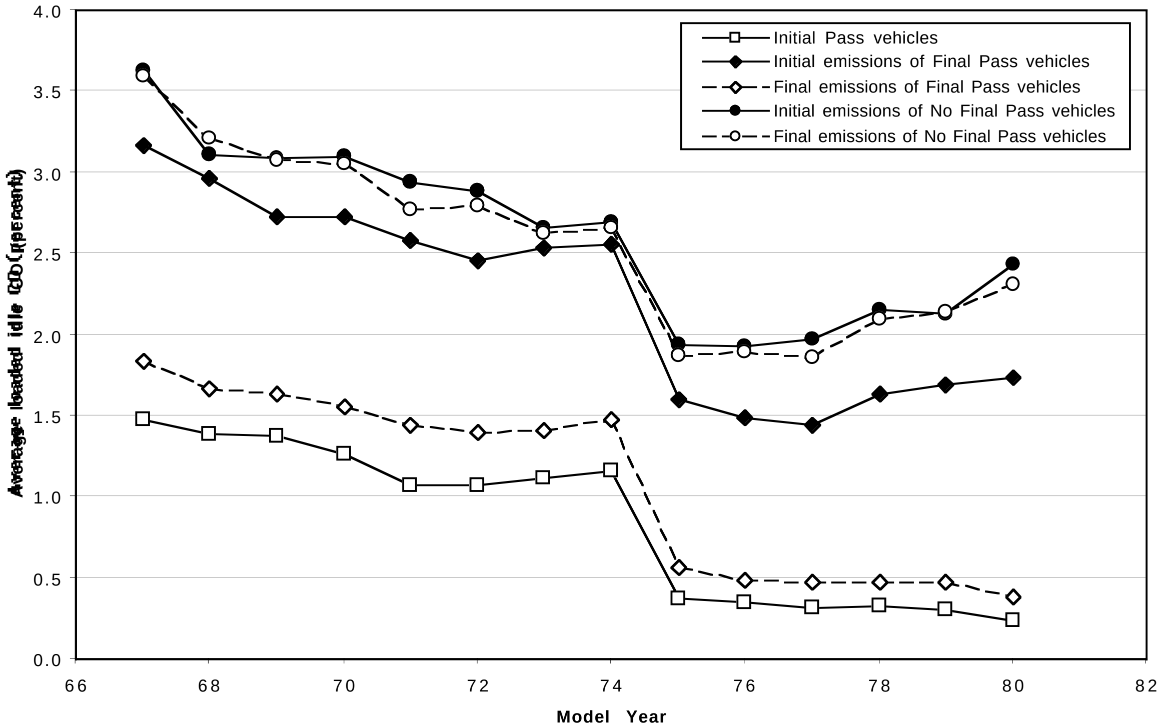


Figure 7. Average Loaded Idle CO by MY and I/M Result
Class 4 Vehicles, 1997 Arizona Idle

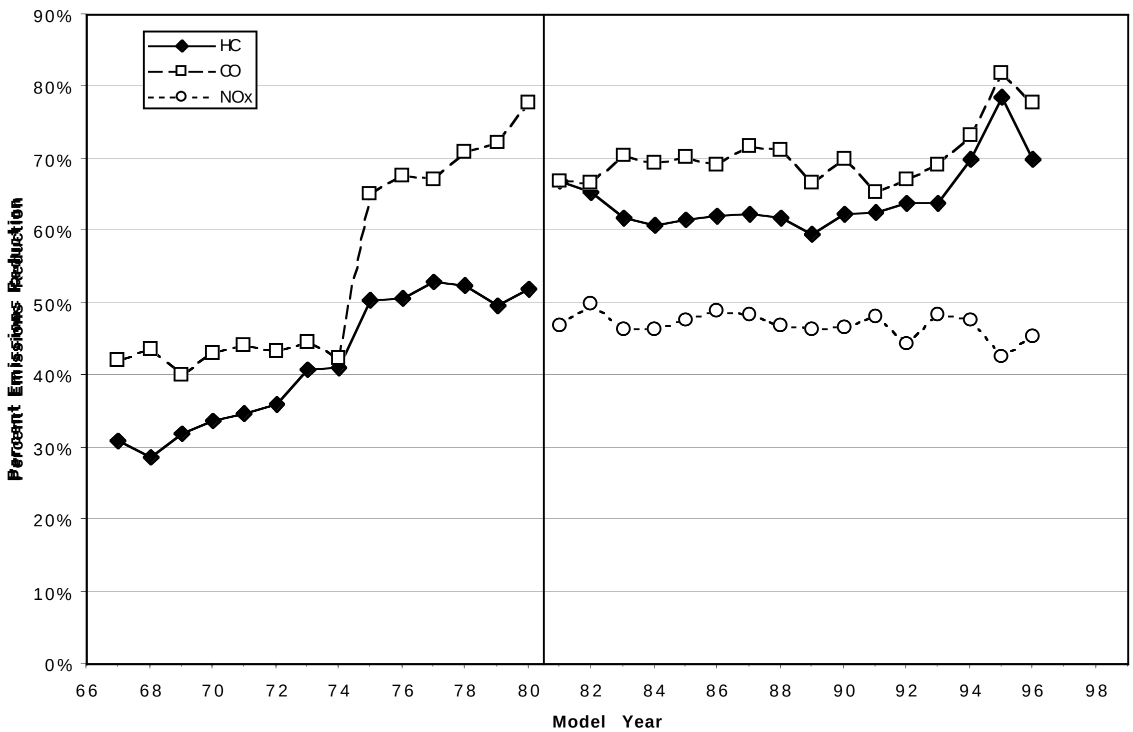


for 1991 and newer cars, NOx emissions are lower for newer cars. It is not clear why the trend in initial CO emissions of Final Pass and No Final Pass cars increases for 1993 and newer cars; this may be the result of out of state cars registering for the first time in Arizona (model year 1996 and newer vehicles already registered in the state were exempted from testing in 1997).

The figures show that Final Pass vehicle emissions are dramatically reduced by the program, at least as measured by program data. However, the emissions of Final Pass vehicles are not brought down to the level of emissions of Initial Pass vehicles. For the most part No Final Pass vehicles have higher initial and final emissions than Final Pass vehicles of the same age. However, older IM240 Final Pass vehicles have higher initial NOx emissions than older No Final Pass vehicles.

Figure 8 presents the percent emissions reduction for each pollutant, by model year, for Final Pass IM240 cars and loaded idle Class 4 vehicles. The figure indicates that the percentage emissions reductions of model year 1981 through 1993 Final Pass vehicles are fairly consistent by model year. HC and CO emission reduction percentages are slightly higher for 1993 and newer cars than for older cars. Percent reductions in loaded idle emissions are larger for model year 1975 through 1980 vehicles, than for older vehicles (loaded idle cutpoints are substantially stricter for 1975 and newer vehicles).

Figure 8. Percent Emissions Reduction by Model Year
Final Pass Cars/Class 4, 1997 Arizona IM240 and Loaded Idle



5. Estimating Effectiveness for the Entire I/M fleet

As discussed above, there are three major limitations of the I/M data that complicate any evaluation of the effectiveness of the overall Phoenix program:

1) One of two different emissions tests, the IM240 or the loaded idle test, is applied to each vehicle, depending on the vehicle’s age. Each test measures vehicle emissions under different driving conditions, and reports emissions in different units. Therefore, emissions results as measured under the two tests are not directly comparable;

2) NOx emissions are not measured during the loaded idle test, therefore NOx emissions for the older fleet subject to loaded idle testing are not available; and

3) The loaded idle fleet is classified differently than the IM240 fleet, making it difficult to consistently weight emissions by annual vehicle miles traveled.

These limitations make it difficult to convert emissions concentrations from loaded idle testing into total mass emissions weighted by vehicle VMT, or the tons per day used for official emissions inventories and state implementation plans. In this section we attempt to determine the contribution of the loaded idle fleet to total I/M fleet emissions, and the tons of emissions reduced by the loaded idle program. We do this by extending the trend of the IM240 emission inventory by model year backward through model year 1967 vehicles, based on our analysis of the effectiveness of the program in reducing emissions of the loaded idle fleet.

Figures 9 and 10 show the trends in IM240 vehicles and their initial emissions in tons per day, respectively. Figure 9 demonstrates that the number of vehicles of all types increases as model year increases; the majority of the IM240 fleet is made up of relatively young vehicles. Figure 10 demonstrates a similar trend for NOx emissions; most of the NOx emissions come from the youngest vehicles. On the other hand, the peak of the HC and CO emissions distributions occurs around mid-1980s vehicles; fewer HC and CO emissions come from the youngest vehicles. These trends are due to the nature of HC and CO vs. NOx emissions. A few extremely high HC and CO emitters account for a relatively large portion of total HC and CO emissions, resulting in dramatically skewed distributions of HC and CO emissions. The range in NOx emissions is much smaller, resulting in a less skewed emissions distribution for NOx. Because NOx emissions are less skewed than HC or CO emissions, the number of vehicles heavily influences the NOx distribution in Figure 10.

Figure 9. Number of Vehicles by Type and Model Year

1997 AZ IM240

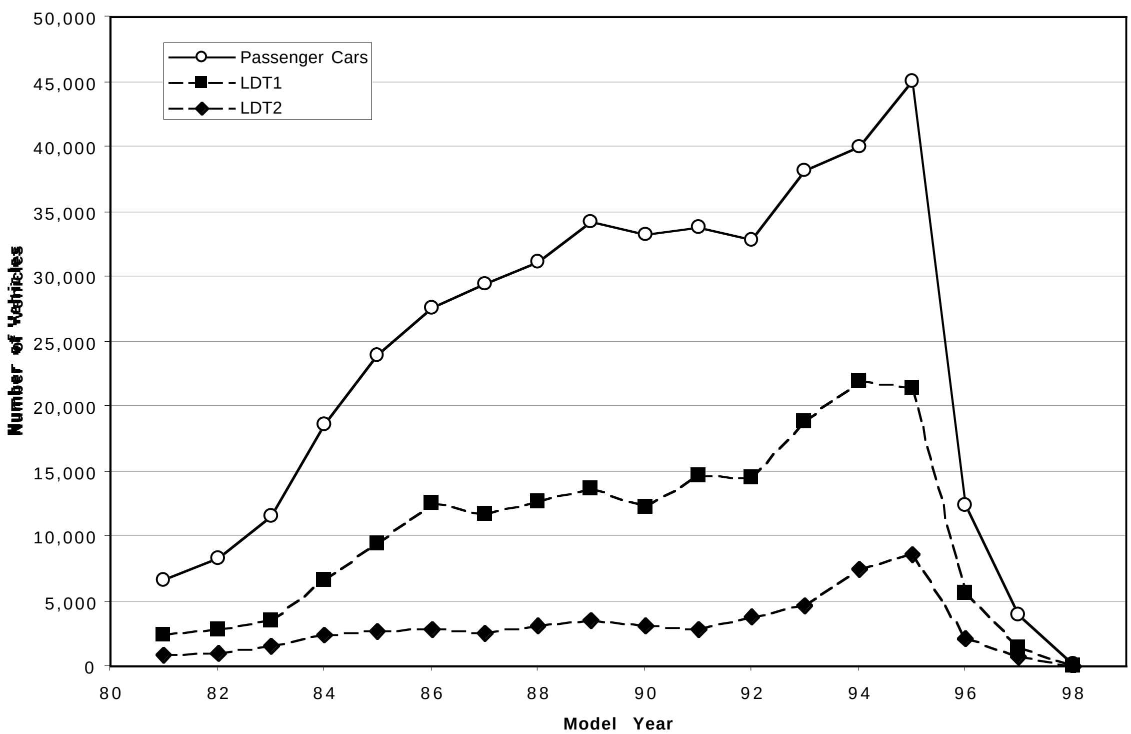


Figure 10. Total Emissions (tons per day) by Model Year

All Vehicle Types, 1997 AZ IM240

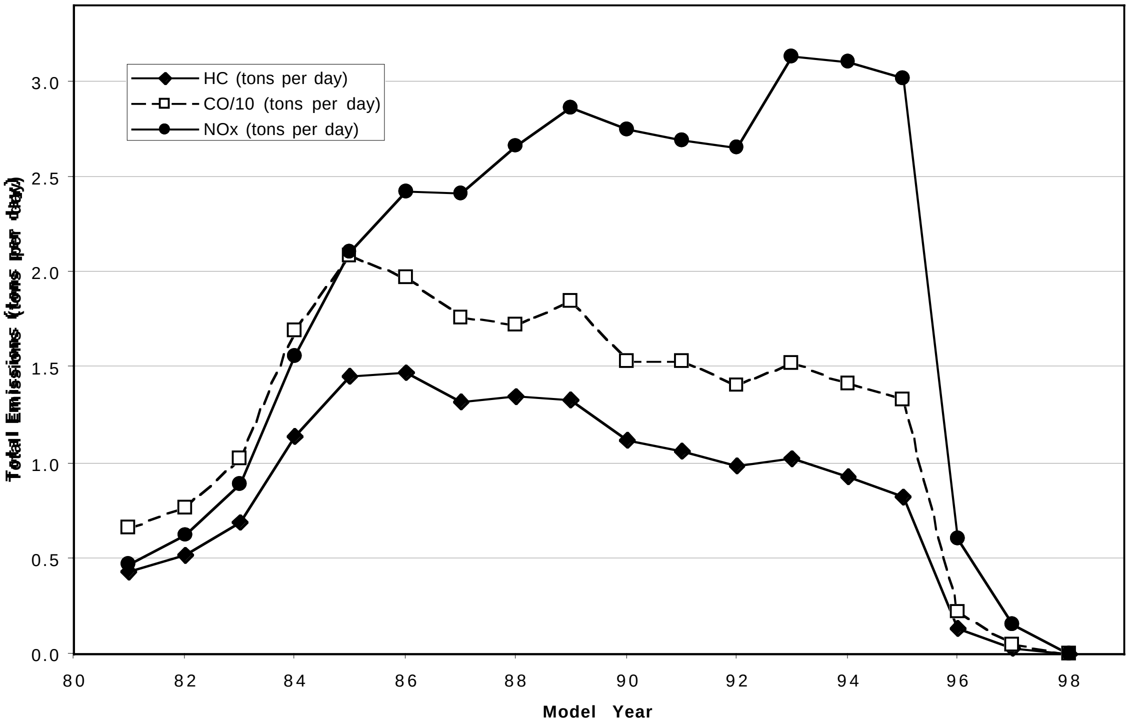
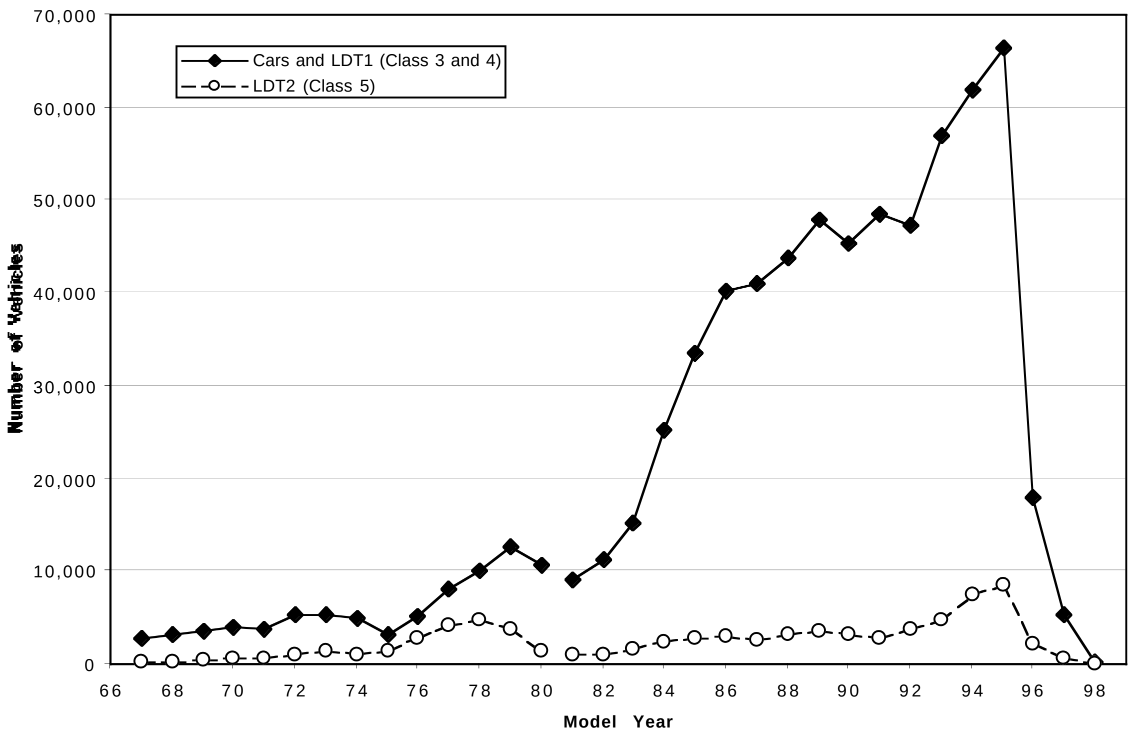


Figure 11 combines the distribution of IM240 vehicles in Figure 9 with the distribution of loaded idle test vehicles. Cars and LDT1 are combined into the same group to match the categories of the loaded idle test fleet (Classes 3 and 4). We see that there are many fewer loaded idle vehicles than IM240 vehicles. However, the vehicle distributions do not match perfectly; there are 20% more 1980 vehicles tested under the loaded idle program than 1981 vehicles tested under the IM240 program (17% more cars and LDT1, and 45% more LDT2). A possible explanation is that motorists perceive the IM240 test as more difficult to pass than the loaded idle test, and relocate their vehicles outside of the I/M area (either legally or illegally) to avoid the tougher IM240 test. However, this would not explain why the distribution of loaded idle vehicles peaks at model years 1978 and 1979, and declines for model year 1980 vehicles. The discrepancy between the number of LDT2 subject to the two tests is particularly disturbing; there are over five times as many model year 1978 LDT2 in the loaded idle fleet than 1981 LDT2 in the IM240 fleet. In fact, not until model year 1993 does the number of IM240 LDT2 approach the number of 1978 loaded idle LDT2.

Figure 11. Number of Vehicles by Type and Model Year
1997 Phoenix I/M Program



Our method to estimate the mass emissions of the loaded idle test vehicles involves taking the distribution of VMT-weighted emissions from these vehicles by model year and scaling it to the shape of the vehicle distribution. Calculating VMT-weighted loaded idle emissions is complicated since the loaded idle vehicles are not classified into cars and LDT1s. EPA's annual VMT assumptions by model year and type are dramatically different for older vehicles; for instance, estimated annual VMT for model year 1968 cars is nearly three times that of model year 1968 LDT1, while estimated annual VMT for model year 1980 cars is almost 40% higher than that of the same age LDT1. Using the car annual VMT weights for all Class 3 and 4 loaded idle vehicles results in an emissions inventory more than 40% greater than if the LDT1 weights are used for all Class 3 and 4 vehicles. We take the average of the car and LDT1 VMT weights for each model year to develop our VMT-weighted emissions for loaded idle vehicles.

Figures 12 through 14 show the new distributions of initial and final emissions by model year for both the loaded idle and IM240 vehicles. Since there are 20% more MY80 vehicles tested on the loaded idle than MY81 vehicles tested on the IM240, we scale the loaded idle emissions distribution so that the MY80 emissions in tons is 20% higher than the MY81 emissions. For NOx emissions from MY79 and older vehicles, we assume a smooth emissions distribution by model year where the emissions of each previous model year are 80% that of the next model year, with the constraint that MY67 vehicles account for 0.1 tons per day NOx. (The assumption of the smooth curve of NOx emissions underestimates the NOx contribution of model year 1979 and 1980 vehicles, but overestimates the contribution of 1975 and 1976 vehicles.) The initial and final emissions distributions by model year for HC, CO and NOx are shown in Figures 12, 13 and 14, respectively.

Figure 12. Estimated Total HC Emissions (tons per day), by Model Year
1997 Phoenix I/M Program

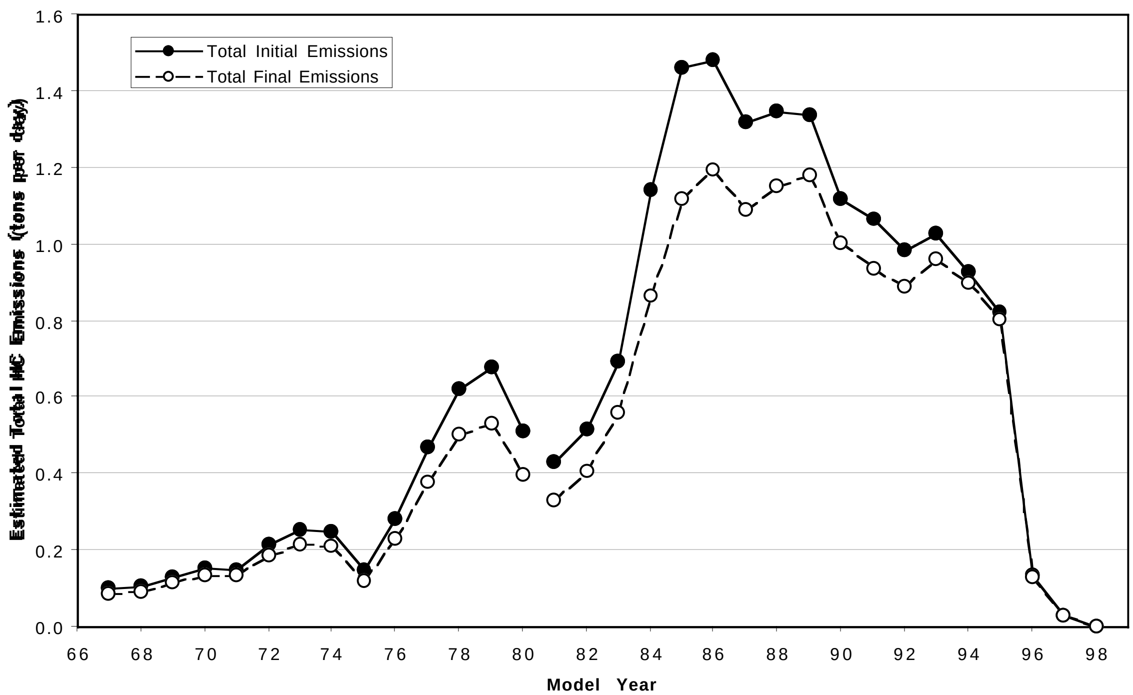


Figure 13. Estimated Total CO Emissions (tons per day), by Model Year
1997 Phoenix I/M Program

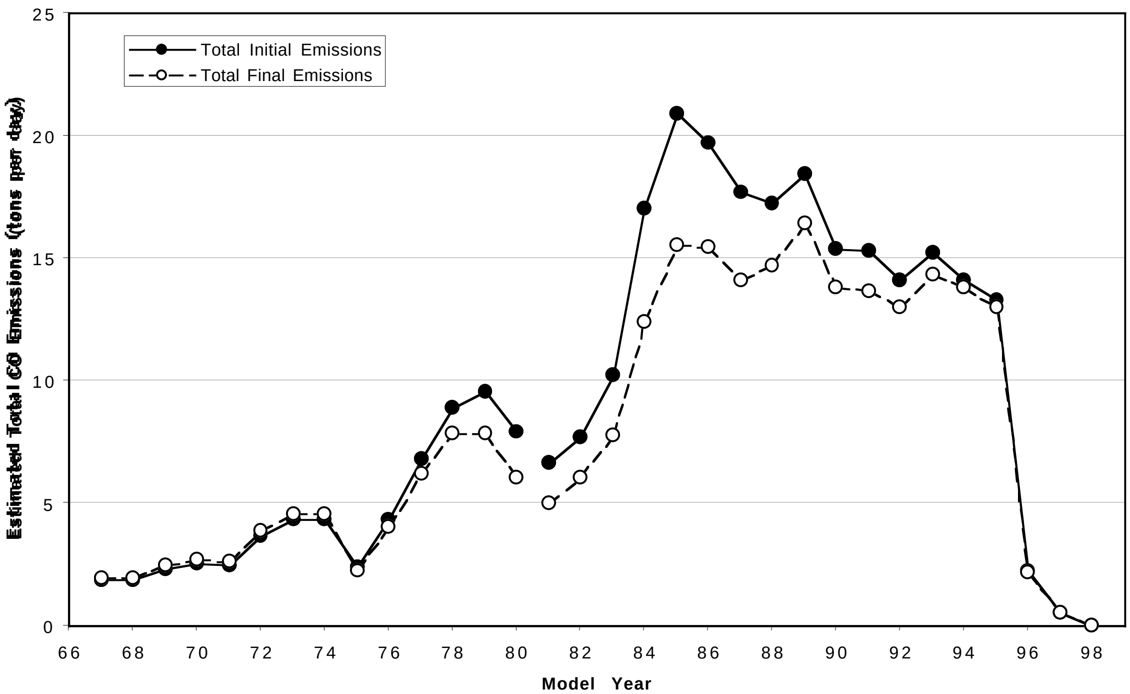
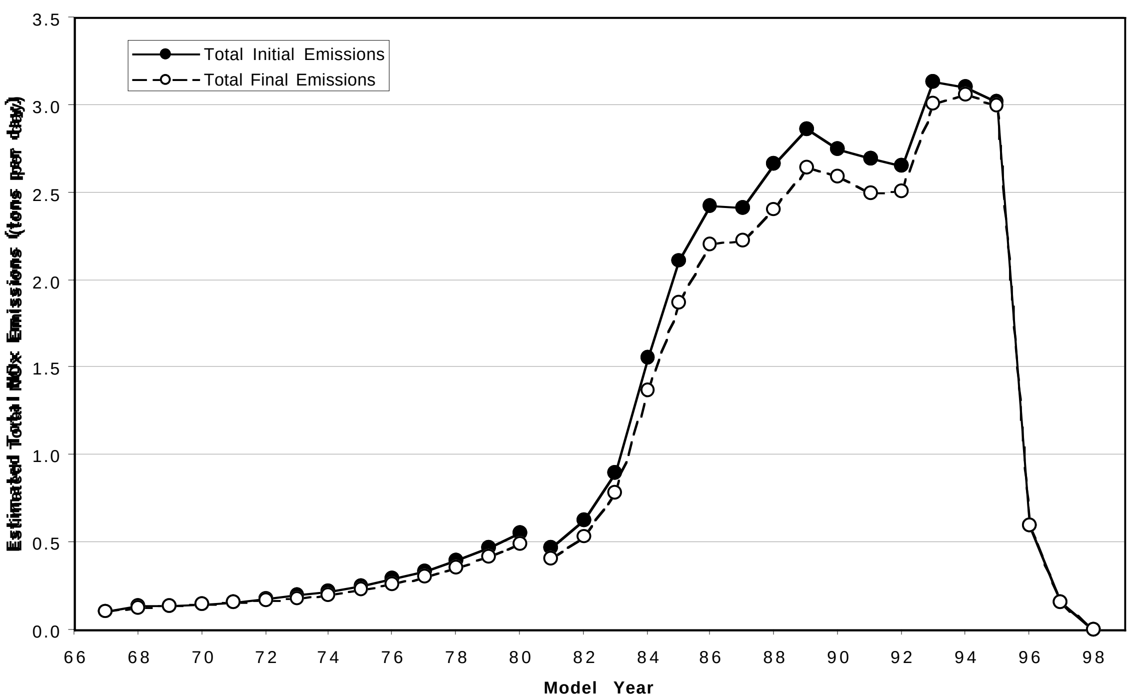


Figure 14. Estimated Total NOx Emissions (tons per day), by Model Year
1997 Phoenix I/M program



The tons per day emissions and emission reductions derived from Figures 12 through 14 are shown in Tables 8 and 9. We estimate that the Phoenix I/M program reduces the emissions of the fleet reporting for I/M by 3.0 tons per day for HC, 38 tons per day for CO, and 2.6 tons per day for NOx. The majority of the estimated emissions reductions comes from the IM240 fleet: 76% for HC, and 88% for CO and NOx. The estimated percent reduction in VMT-weighted emissions is 15% for HC, 13% for CO, and 7% for NOx.

Table 8. Estimated Total Emissions by I/M Fleet, Tons per Day Weighted by Annual VMT

	Fleet	Number	HC (tpd)		CO (tpd)		NOx (tpd)	
			Initial	Final	Initial	Final	Initial	Final
Total Emissions	Idle	106,000	4.1	3.3	63.3	58.8	3.6	3.2
	IM240	670,768	15.8	13.5	225.6	191.7	34.1	31.9
	Total	776,768	19.9	16.9	288.9	250.4	37.7	35.1
Distribution of Emissions	Idle	14%	20%	20%	22%	23%	9%	9%
	IM240	86%	80%	80%	78%	77%	91%	91%
	Total	100%	100%	100%	100%	100%	100%	100%

Note: Absolute tons of emissions may not be comparable to official emissions inventories, due to conversion of fast pass/fast fail emissions to full IM240 emissions and exclusion of vehicles with invalid VINs, multiple initial tests, or that do not report for I/M testing.

Table 9. Estimated Emission Reductions by I/M Fleet, Tons per Day Weighted by Annual VMT

	Emission Reductions			Distribution of Emission Reductions			Percent Reduction		
Fleet	HC	CO	NOx	HC	CO	NOx	HC	CO	NOx
Idle	0.7	4.5	0.3	24%	12%	12%	18.0%	7.1%	8.8%
IM240	2.3	34.0	2.3	76%	88%	88%	14.4%	15.1%	6.6%
Total	3.0	38.5	2.6	100%	100%	100%	15.2%	13.3%	6.8%

Note: Absolute tons of emissions may not be comparable to official emissions inventories, due to conversion of fast pass/fast fail emissions to full IM240 emissions and exclusion of vehicles with invalid VINs, multiple initial tests, or that do not report for I/M testing.

6. Accounting for No Final Pass Vehicles

As noted above, about 26% of the vehicles that failed their initial IM240 test in 1997 never received a subsequent passing test through March 1998. It is possible that the program induced the owners of these vehicles to sell them or otherwise remove them from the I/M area. If so, the removal of these vehicles should be counted as a reduction in emissions attributable to the presence of the I/M program. However, if these vehicles are merely illegally re-registered outside of the I/M area, but continue to be driven regularly within the I/M area, the emissions of these vehicles must continue to be counted in the I/M area emission inventory. Whether or not these vehicles are still being driven in the I/M area does not affect estimates of emissions reductions on a per vehicle basis, as shown in Table 1. However, properly accounting for these vehicles will affect estimates of emissions reductions reported on an absolute tonnage basis, as presented in Table 3 (as well as Tables 8 and 9).

Table 3 assumes that all of the IM240 No Final Pass vehicles continue to be driven in the I/M area, and contribute to the "final" I/M emissions inventory. Table 10 assumes that none of these vehicles continue to be driven in the I/M area; these vehicles contribute to the "initial" I/M emissions inventory, but are removed from the "final" I/M emissions inventory. Removing all of the No Final Pass vehicles from the I/M area has a dramatic effect on the estimated effectiveness of the IM240 program, nearly doubling the percent reductions to 27% for HC and CO and to 11% for NOx, and the tonnage reductions to 4 tons per day for HC and NOx, and 61 tons per day for CO.

Table 10. Total Emissions and Percent Reduction, Weighted by Annual VMT (excludes all 1997 No Final Pass vehicles from final emissions)

Type	Number	Total Emissions (Tons per Day)						Percent Reduction		
		HC		CO		NOx				
		Initial	Final	Initial	Final	Initial	Final	HC	CO	NOx
Cars	414,173	8.7	6.0	125.7	82.5	18.8	16.1	31.2%	34.4%	14.2%
LDT1	182,608	5.1	4.0	72.9	59.8	10.6	9.6	20.7%	18.0%	9.1%
LDT2	52,904	2.0	1.6	26.9	22.0	4.8	4.5	21.0%	18.3%	5.5%
All	649,685	15.8	11.6	225.6	164.3	34.1	30.2	26.5%	27.2%	11.4%
Reduction	*21,084*		*4.2*		*61.3*		*3.9*			

Note: Absolute tons of emissions may not be comparable to official emissions inventories, due to conversion of fast pass/fast fail emissions to full IM240 emissions and exclusion of vehicles with invalid VINs, multiple initial tests, or that do not report for I/M testing.

Clearly a better understanding of the No Final Pass vehicles, and how many of them continue to be driven in the I/M area, is needed to properly estimate the effectiveness of the Arizona I/M program. In an earlier analysis we matched remote sensing data from 1996 and 1997 with 1995 and 1997 I/M test records (Wenzel, 1999b). About 30% of the 1995 No Final Pass (through March 1996) vehicles reported for their next scheduled I/M test in 1997. We compared the fraction of "1995 No Final Pass/tested in 1997" vehicles seen by remote sensing to the fraction of "1995 No Final Pass/not tested in 1997" vehicles seen by remote sensing. 7% of the fleet of vehicles reporting for testing in 1997 were seen by remote sensing over 2 years after their 1995 I/M test, while only 2% of the fleet that did not report for testing in 1997 were seen by remote sensing. The ratio of these two percentages (2% / 7%) gives us an estimate for the fraction of "1995 No Final Pass/not tested in 1997" vehicles still being driven in the I/M area: 27%.

If the fleet of vehicles initially tested in 1997 is similar to the fleet of vehicles initially tested in 1995, then we can assume that 30% of the 1997 No Final Pass vehicles will return for testing in 1999, and therefore will continue to be driven in the I/M area. In addition, of the 70% that will not report for testing in 1999, 30% will continue to be driven in the I/M area, or 20% (0.30 * 0.70 = 0.21) of all 1997 No Final Pass vehicles. Therefore, we estimate that about half (30% + 20%) of all 1997 No Final Pass vehicles continue to be driven in the I/M area more than 2 years after their 1997 I/M test. Table 11 shows the effect on total emissions and the percent reduction attributable to the I/M program, assuming that half of the 1997 No Final Pass vehicles continue to be driven in the I/M area. Under this assumption, the I/M program reduces HC and CO emissions by about 21%, and NOx emissions by about 9%; the tonnage reductions are 3 tons per day for HC and NOx, and 48 tons per day for CO.

Table 11. Total Emissions and Percent Reduction, Weighted by Annual VMT (excludes half of 1997 No Final Pass vehicles from final emissions)

Type	Number	Total Emissions (Tons per Day)						Percent Reduction		
		HC		CO		NOx				
		Initial	Final	Initial	Final	Initial	Final	HC	CO	NOx
Cars	422,635	8.7	6.7	125.7	92.8	18.8	16.7	23.3%	26.2%	10.9%
LDT1	184,247	5.1	4.2	72.9	62.3	10.6	9.8	16.8%	14.6%	7.6%
LDT2	53,346	2.0	1.7	26.9	22.9	4.8	4.5	17.6%	15.1%	4.6%
All	660,227	15.8	12.6	225.6	178.0	34.1	31.0	20.5%	21.1%	9.0%
Reduction	*10,542*		*3.2*		*47.6*		*3.1*			

Note: Absolute tons of emissions may not be comparable to official emissions inventories, due to conversion of fast pass/fast fail emissions to full IM240 emissions and exclusion of vehicles with invalid VINs, multiple initial tests, or that do not report for I/M testing.

Because of the limitations of the loaded idle test data, and the time constraints of this project, we have not estimated the effect of loaded idle No Final Pass vehicles permanently leaving the Phoenix area on the overall emissions inventory.

7. Other Issues

This analysis uses emissions test results from the Phoenix I/M program to evaluate the effect of the program in reducing vehicle emissions. The analysis compares the initial tests of vehicles with any subsequent tests to estimate emission reductions, both in terms of percent and in terms of tons of pollutants. A single year of I/M program data can give an indication of the initial effectiveness of vehicle repairs performed under the program. However, there are several limitations with basing a program evaluation solely on emissions test results from the program itself:

- The emissions difference between the initial and final tests does not capture all of the emissions reductions that the program may be causing; dirty vehicles may leave the area, motorists may take better care of their vehicles, and motorists may pay more attention to purchasing cleaner vehicles as a result of the I/M program.

- Some of the emissions difference between the initial and final tests may not be due to repair at all. For example, more extensive preconditioning can cause a failed vehicle to pass a retest without repairs being made. Or a vehicle may pass a retest when environmental conditions (ambient temperature and humidity) are more favorable. Or the effect of regression to the mean may cause a moderately high emitter to have slightly lower emissions on a retest and pass. These are three of several possible explanations for why the difference between the initial and final readings may be overestimating the amount of emissions reduction.

- In-program data measure the effectiveness of any vehicle repairs immediately after such repairs have been made. In effect, such an analysis assumes that all repairs made remain effective. However, repaired components on some vehicles may fail shortly after testing, or the repair may not address the underlying cause of the higher emissions. Evaluations based on in-program data do not account for the effect of insufficient, or temporary, repair of vehicles.

- As discussed above, the presence of an I/M program may induce some owners to register their vehicles outside of the I/M area, particularly if they suspect their vehicle will fail an I/M test. If these vehicles are indeed high emitters, and they are legitimately registered outside of the I/M area (and no longer driven in the I/M area), then area emissions will have been reduced. However, if these high emitter vehicles were re-registered merely to avoid I/M testing, and continue to be driven in the I/M area, area emissions will be unchanged. Evaluations using in-program data cannot account for whether vehicles re-registered outside of the program area are high emitters, and what fraction of them continue to be driven in the I/M area, contributing to area emissions inventories.

- Because the I/M test is scheduled, drivers may make temporary repairs or adjustments to vehicles immediately prior to testing. If these repairs result in permanent emissions reductions, in-program data will underestimate the effect of the program in reducing these emissions. If these are merely adjustments made to pass the I/M test, with the vehicles readjusted after passing, program data will correctly measure the percent emissions reduction (none) but will underestimate total fleet emissions.

Some of these issues can be addressed using multiple years of program data. For instance:

- The long-term effectiveness of repairs made to vehicles can be determined by tracking individual vehicles participating in the program over several test cycles. An earlier analysis of 1995 and 1997 data from the Arizona I/M program indicates that 37% of the vehicles that failed their initial test in 1995 but passed a subsequent retest failed their next regularly-scheduled test in 1997. The repeat failure rate ranges from under 15% for newer vehicles to nearly 45% for the oldest vehicles. Of the vehicles that failed in both years, about half failed for the same combination of pollutants in both years, suggesting that, for many vehicles, the repairs made in 1995 did not address the underlying causes of high emissions (Wenzel, 1999a).

- Individual vehicles that are not tested in subsequent I/M test cycles (either due to registering outside of the I/M area, or to otherwise avoiding the I/M program) can be identified. Vehicles that have migrated into the I/M program can also be identified, and their emissions compared with those that have participated in the program. The earlier analysis found that 40% of all vehicles tested in 1995 did not return for testing in 1997. The vehicles that did not report for testing in 1997 tended to be older, and have higher emissions, than the vehicles that did reported for testing in both years. Similarly, about half of the vehicles that were tested in 1997 were not tested in 1995. Of these not tested in 1995, half were either: MY94 and older out of state cars newly registered in Arizona (23%); MY95 cars exempted from testing in 1995 (18%); or MY96 and newer cars voluntarily tested in 1997 (8%). The vehicles tested in 1997 but not in 1995 tended to have higher emissions than the vehicles tested in both years.

On-road emissions testing, either using remote sensing data or roadside testing of vehicles randomly pulled over, can also be used to address some of these issues. In particular, on-road emissions testing can be used in two ways to evaluate I/M program effectiveness:

1) On-road emissions testing programs measure vehicles at different times relative to their last I/M test. Therefore these data can be used to estimate how quickly repair effectiveness diminishes over time, as well as how much repair is made just prior to the I/M test (Wenzel, 1999b).

2) Remote sensing programs measure almost every vehicle that drives by the instrument, regardless of whether it is participating in the I/M program. Remote sensing data therefore can be used to estimate the number and emissions of vehicles legally exempted from, or illegally avoiding, the I/M program, as well as estimating their emissions. In addition, remote sensing data can identify individual vehicles that never complete the current I/M cycle, or that do not report for testing in a subsequent test cycle, but are still being driven in the I/M area.

8. Summary

In this report we use emissions test result data from 1997 to evaluate the effectiveness of the enhanced I/M program in reducing vehicle tailpipe emissions in Phoenix, Arizona. Because the program requires a loaded idle, rather than IM240, test for 1980 and older vehicles, we analyze the effectiveness of the program on the two fleets of vehicles separately. The analysis does not consider the effect of the I/M program on reducing evaporative HC emissions. Because Arizona allows vehicles to fast pass or fast fail the IM240 test, we must convert IM240 “short test” results to full IM240 test equivalents. The relatively simple method we use to make this conversion is comparable to other more detailed methods.

Comparison of initial and final IM240 tests indicates that the program is reducing the average per vehicle emissions by 16% for HC, 17% for CO, and 7% for NOx, for the entire vehicle fleet. After weighting per vehicle emissions by estimated annual miles traveled, the fleetwide emissions reductions are 2.3 tons per day (14% reduction) for HC, 34 tons per day (15% reduction for CO), and 2.3 tons per day (7% reduction) for NOx. CO and NOx reductions appear to be substantially larger for cars than for light duty trucks. Per vehicle emissions of the loaded idle fleet are reduced by 15% for HC and 23% for CO.

About 11% of all vehicles fail their initial IM240 emissions test; the failure rate is slightly higher for passenger cars (12%) than for light duty trucks (8%). The initial failure rate for the loaded idle test is 37%. Of the vehicles that fail their initial test, only 70% received a final passing test through March 1998; 30% did not receive a final passing test through March 1998. Because waivered vehicles are not identified in the data, the actual percentage of No Final Pass vehicles is likely to be closer to 26%. The percentage of No Final Pass cars is greater than the percentage of No Final Pass trucks.

The percent reductions in loaded idle emissions for Final Pass vehicles tend to increase by model year, with larger reductions for newer vehicles. There is a large increase in percent reduction for model year 1974 through 1980 vehicles, presumably due to stricter cutpoints applied to those vehicles. The percentage reductions of IM240 Final Pass vehicles from model years 1981 through 1993 are fairly constant by model year. HC and CO emission reduction percentages tend to increase after model year 1993.

We use a relatively crude method to estimate total emissions and emission reductions in tons per day for the loaded idle fleet, in order to estimate the tonnage reductions for the entire Phoenix I/M program. We estimate that the program reduces the emissions of the fleet reporting for I/M by 3.0 tons per day for HC, 38 tons per day for CO, and 2.6 tons per day for NOx. The majority of the estimated emissions reductions comes from the IM240 fleet: 76% for HC, and 88% for CO and NOx. The estimated percent reduction in total emssions is 15% for HC, 13% for CO, and 7% for NOx.

The estimated effectiveness of the I/M program depends on whether the No Final Pass vehicles have been permanently removed from the I/M area, or if they continue to be driven in the I/M area. The effectiveness of the program on the IM240 fleet nearly doubles if one assumes that all IM240 No Final Pass vehicles have been permanently removed from the area. Analysis of 1995 IM240 test data and remote sensing data indicate that about half of the No Final Pass vehicles continue to be driven in the I/M area. If this information is correct for vehicles tested in 1997, the 1997 I/M program resulted in a 22% reduction in HC and CO, and a 9% reduction in NOx from the IM240 fleet. These percentage reductions are equivalent to 3.0 tons per day for HC and NOx, and 48 tons per day for CO.

Analysis of a single year of I/M program test data can only provide a partial understanding of the program's effectiveness in reducing emissions. Tracking of individual vehicles over several I/M cycles can reveal important information on long-term effectiveness of vehicle repair, and changes in the fleet reporting for I/M testing. In addition, an independent source of on-road emissions tests, such as from a remote sensing measurement program, can provide additional information on repair effectiveness, the effect of pre-test repairs on emissions, and the number and emissions of vehicles avoiding the I/M program.

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Appendix A.

Converting Fast Pass/Fast Fail Emissions Results to Full IM240 Equivalents
Unpublished memo
Tom Wenzel, Lawrence Berkeley National Laboratory
June 17, 1999

At least 4 methods have been used to convert fast-pass/fail emissions to full IM240 emissions: 1) a method developed by LBNL for use in analyzing the Arizona I/M program (LBNL; Wenzel, 1997); 2) a method developed by Peter McClintock of Applied Analysis, with input from Rob Klausmeier and the Colorado Department of Public Health and Environment, for use in the Colorado I/M program (PM; McClintock, 1998)[8]; 3) a method developed by Resources for the Future, also for use in analyzing the Arizona program (RFF; Ando et al, 1998), and 4) a method developed by EPA using data from Wisconsin and applied to Ohio fast pass data EPA; (EPA; Enns, 1999, and personal communication). The LBNL method is based on the average ratio of emissions at each second to full test emissions from a sample of 4,000 vehicles receiving the full IM240 in Arizona in 1992.[9] The LBNL method involves dividing emissions at a given second by a correction factor, based only on the second of testing (and not on other variables, such as vehicle age or type). The McClintock and RFF methods are similar; they rely on regression models generated for many subsets of the data. The McClintock method accounts for vehicle age and type, while the RFF method accounts for vehicle age and the product of the vehicle age and emissions level at a given second. The McClintock coefficients were calculated for 10 second intervals in the IM240 trace; coefficients for interlying seconds are determined by interpolation. The RFF method estimates <u>negative</u> emissions values for some vehicles with very low emissions at second 31. The EPA method is based on a single regression equation for the entire vehicle fleet. The equation includes coefficients for the log of fast pass emissions, the last second of the test, and dummy variables for whether the vehicle is fuel injected or carbureted, a car or a truck, and for 14 model years.[10]

This memo examines the accuracy of such methods in predicting full IM240 emissions. First, we compare the accuracy of each of the three methods on a sample of vehicles whose full test emissions are known. Then we apply the PM and LBNL method to Wisconsin data, to see what effect different methods have on fleet emissions estimates. Finally, we evaluate the accuracy of the LBNL method by comparing the distribution of emissions of fast pass/fast fail vehicles with that of the random sample of vehicles receiving the full IM240.

Comparison of Three Methods

We used the random sample (Jan-June 1996) of vehicles given a full IM240 in Arizona to test the accuracy of three different methods in accurately predicting full IM240 emissions from

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8. Developed in late 1995 and early 1996 with inputs from Rob Klausmeier and CDPHE.
9. The testing was conducted by Automotive Testing Laboratory, under contract with EPA. The vehicles tested may not be a random sample of vehicles.
10. We could not perfectly match EPA's results when we applied EPA's methodology to the Ohio data. We calculated the Ohio fleet emissions to be 18% higher for HC, 7% higher for CO, and 8% higher for NOx than as calculated by EPA, apparently using the same conversion method.

vehicles passing after only 30 seconds of testing. We first identified which vehicles in the random sample would have passed EPA-recommended fast-pass cutpoints at second 30; there are 2,197 such passenger cars in the random sample. Then, we calculated what each vehicle's estimated full IM240 emissions would be under each conversion method. We analyzed cars from model years 1983 to 1990, and model years 1991 and newer, separately, since different fast pass cutpoints are applied to these two model year groups. (A more thorough analysis would predict at which second each vehicle would have fast-passed or fast-failed the IM240, and then make the adjustments to all of the vehicles in the sample. We focus here on the vehicles that fast-pass at second 30 to simplify the analysis, and because the majority of vehicles that fast-pass pass at this second.)

Table 1 shows the average emissions for these groups of vehicles over the full IM240 test, as measured under the program and as estimated by the three conversion methodologies. (The EPA method is calculated for MY81-94 cars only; the analysis was not applied to the 297 MY95 and newer cars in the Arizona sample. The EPA method was not applied to 77 cars in the MY83-90 group for which type of fuel delivery system was not readily available for the Arizona data. Restricting the analysis to only those cars that can be analyzed using the EPA method does not change the results.) The method that best predicts the emissions for each vehicle group and pollutant is noted in bold type in the table. In general, the LBNL method tends to underestimate the full test emissions of fast-passed cars; this underestimation is greatest for CO emissions, and for emissions from older vehicles. On the other hand, the PM method tends to overestimate emissions. The RFF method predicts emissions from older cars more accurately than from newer cars, while the LBNL method predicts emissions from newer cars more accurately. The RFF method estimates that full test NOx emissions of MY91+ cars are only 30% of their measured emissions; this large underestimation is because the RFF method predicts that over 35% of these vehicles would have had negative NOx emissions over the full IM240 (rounding the emissions of these vehicles to zero raises the fleet NOx emissions to 0.14 gpm, and raises the ratio of estimated to measured NOx to 0.31). When applied to Arizona data, the EPA method drastically underestimates emissions of all three pollutants, in both model year groups.

Table 1. Measured and Predicted full IM240 Emissions under Four Prediction Methods

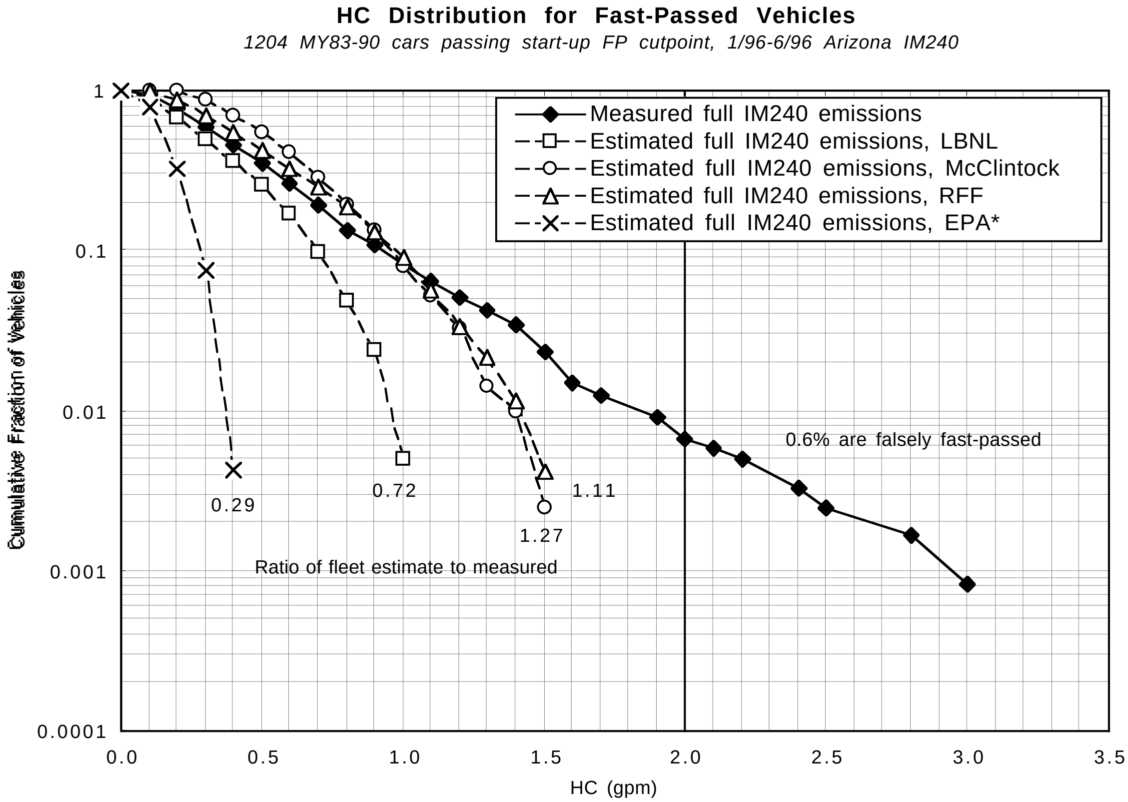
	Average emissions, gpm			Ratio of estimated to measured		
	HC	CO	NOx	HC	CO	NOx
MY83-90 (n=1,204)						
Measured	0.42	6.85	1.21	1.00	1.00	1.00
LBL	0.30	3.65	0.87	0.72	0.53	0.72
PM	0.53	9.55	1.14	1.27	1.40	**0.95**
RFF	0.46	7.05	0.91	**1.11**	**1.03**	0.76
EPA*	0.12	2.19	0.33	0.29	0.32	0.27
MY91+ (n=993)						
Measured	0.10	1.93	0.45	1.00	1.00	1.00
LBL	0.10	1.35	0.43	**1.01**	0.70	0.95
PM	0.15	3.35	0.46	1.45	1.74	**1.01**
RFF	0.08	1.56	0.11	0.79	**0.81**	0.24
EPA**	0.05	0.76	0.23	0.49	0.40	0.51

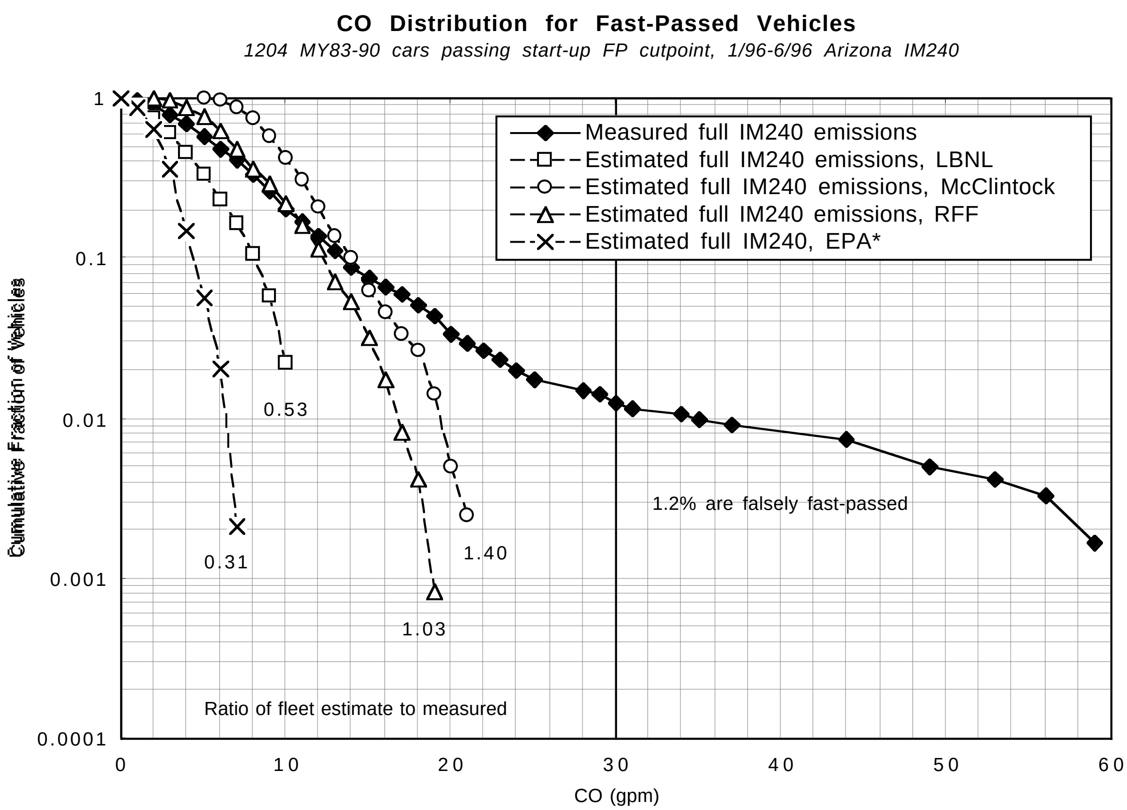
*The EPA method relies on type of fuel delivery system (carbureted or fuel injected); the analysis was not applied to 77 cars for which fuel delivery system was not readily available.

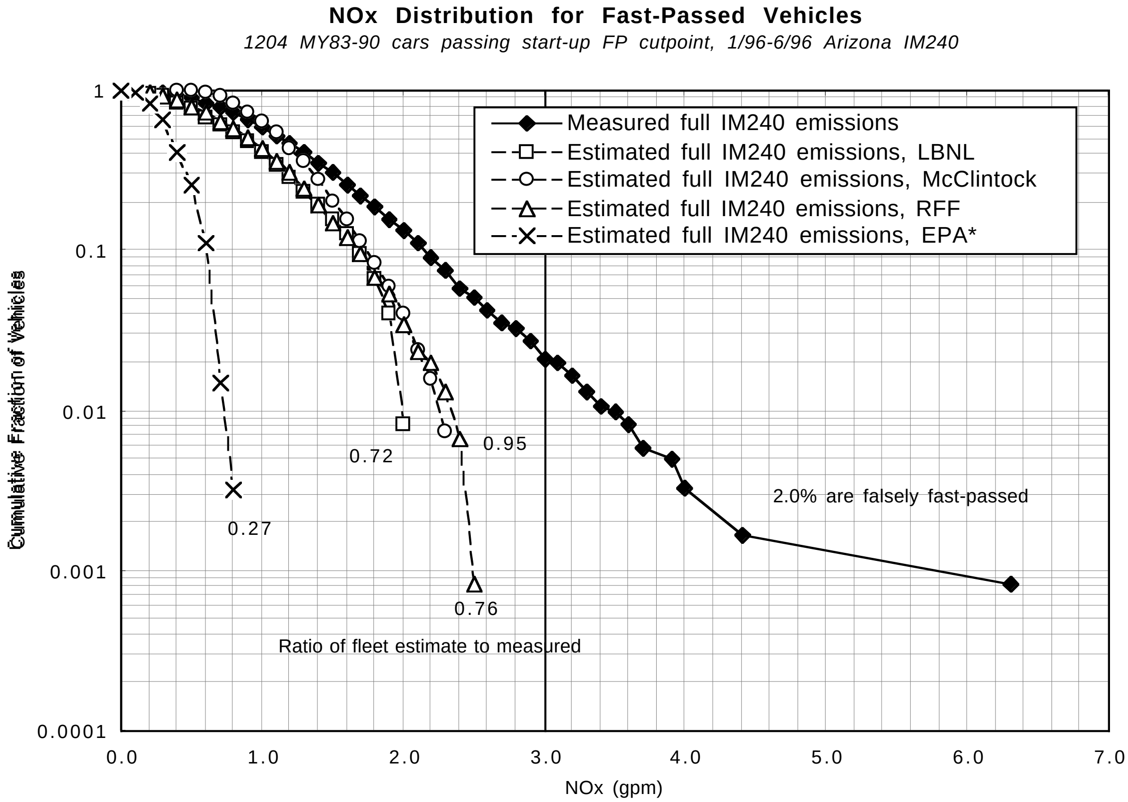
**The EPA method is calculated for MY81-94 cars only; the analysis was not applied to the 297 MY95 and newer cars in the Arizona sample.

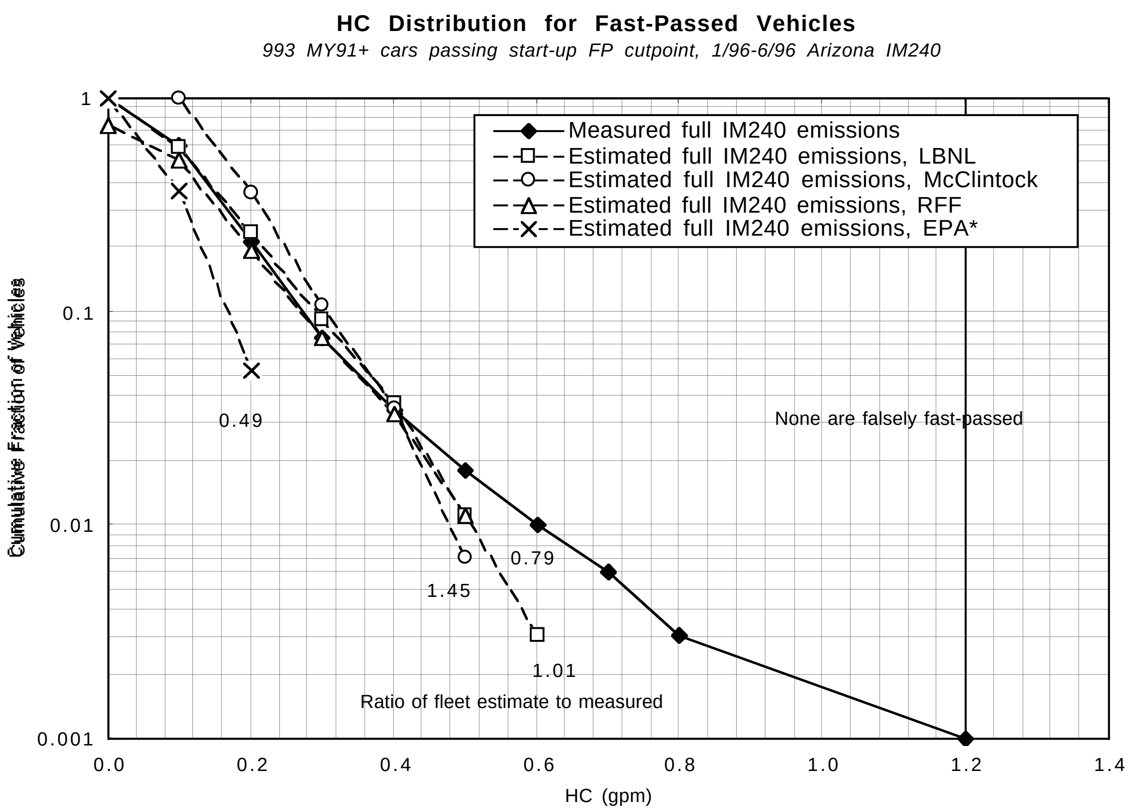
The following six figures show the distribution of emissions, as measured and as estimated based on the three prediction methods. The figures also report the ratio of the estimated to the measured emissions for all vehicles, from Table 1 above. A few of the vehicles that would have been fast-passed (i.e. that had emissions at second 30 lower than the fast pass cutpoints) had emissions higher than the cutpoints applied to the full IM240 test. The figures indicate the portion of all vehicles that would have been falsely fast-passed if the fast-pass cutpoints were applied. For instance, none of the MY91 and newer cars would have been fast-passed for NOx, but 2 percent (24 cars) of the MY83-90 cars would have been falsely fast-passed for NOx.

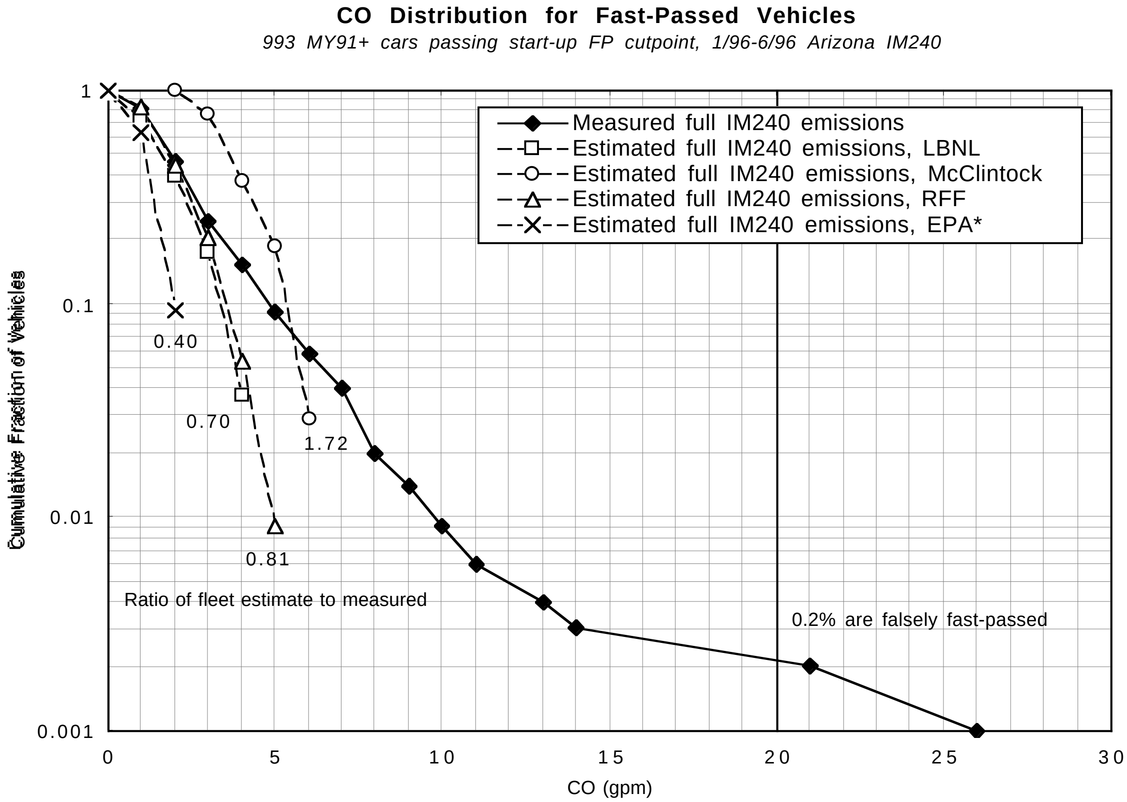
It should be noted that the RFF method was developed using some of the data used in this evaluation, and therefore should be expected to most accurately predict full test emissions. (The PM method was developed using Colorado IM240 data, the LBNL method was developed using earlier IM240 tests conducted in Tucson by Automotive Testing Laboratories, and the EPA method was developed using Wisconsin IM240 data.)

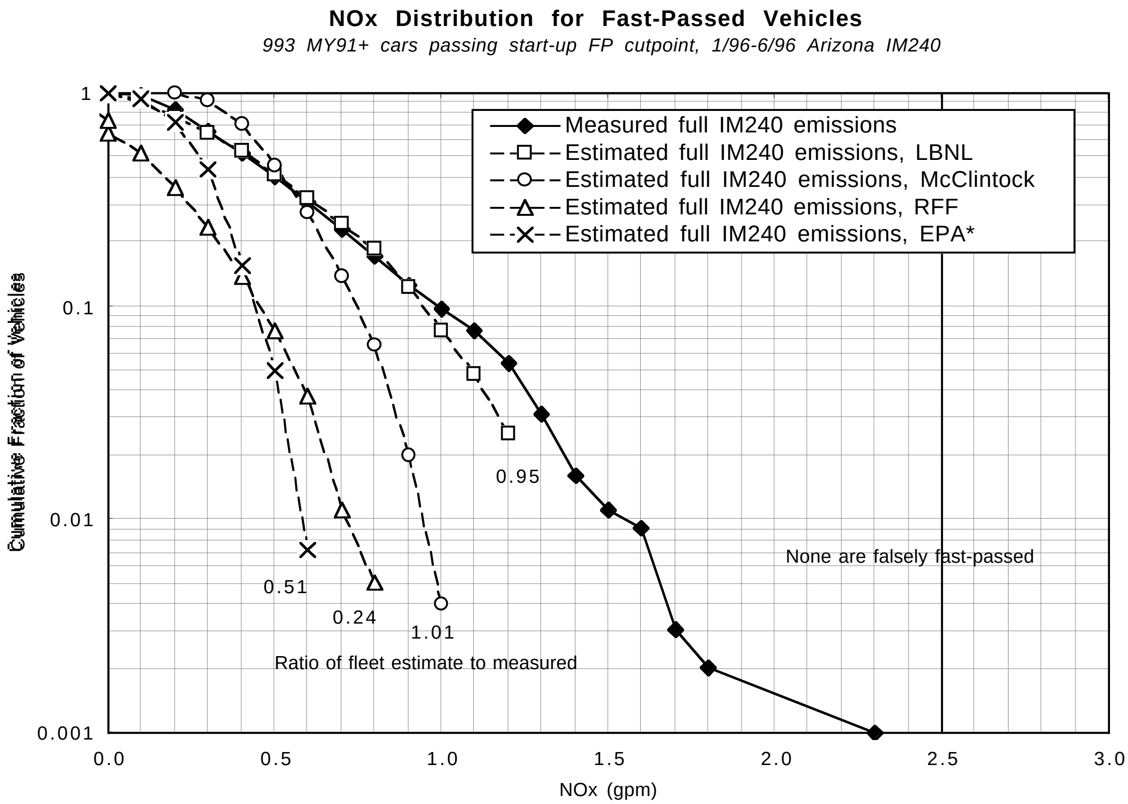

HC Distribution for Fast-Passed Vehicles
1204 MY83-90 cars passing start-up FP cutpoint, 1/96-6/96 Arizona IM240
Measured full IM240 emissions
Estimated full IM240 emissions, LBNL
Estimated full IM240 emissions, McClintock
Estimated full IM240 emissions, RFF
Estimated full IM240 emissions, EPA*
Cumulative Fraction of Vehicles
HC (gpm)
0.6% are falsely fast-passed
Ratio of fleet estimate to measured
0.29
0.72
1.11
1.27


CO Distribution for Fast-Passed Vehicles
1204 MY83-90 cars passing start-up FP cutpoint, 1/96-6/96 Arizona IM240
Measured full IM240 emissions
Estimated full IM240 emissions, LBNL
Estimated full IM240 emissions, McClintock
Estimated full IM240 emissions, RFF
Estimated full IM240, EPA*
Cumulative Fraction of Vehicles
CO (gpm)
1.2% are falsely fast-passed
Ratio of fleet estimate to measured
0.53
0.31
1.40
1.03


NOx Distribution for Fast-Passed Vehicles
1204 MY83-90 cars passing start-up FP cutpoint, 1/96-6/96 Arizona IM240
Measured full IM240 emissions
Estimated full IM240 emissions, LBNL
Estimated full IM240 emissions, McClintock
Estimated full IM240 emissions, RFF
Estimated full IM240 emissions, EPA*
Cumulative Fraction of Vehicles
NOx (gpm)
0.27
0.72
0.95
0.76
2.0% are falsely fast-passed
Ratio of fleet estimate to measured


HC Distribution for Fast-Passed Vehicles
993 MY91+ cars passing start-up FP cutpoint, 1/96-6/96 Arizona IM240
Measured full IM240 emissions
Estimated full IM240 emissions, LBNL
Estimated full IM240 emissions, McClintock
Estimated full IM240 emissions, RFF
Estimated full IM240 emissions, EPA*
Cumulative Fraction of Vehicles
HC (gpm)
0.49
None are falsely fast-passed
0.79
1.45
1.01
Ratio of fleet estimate to measured


CO Distribution for Fast-Passed Vehicles
993 MY91+ cars passing start-up FP cutpoint, 1/96-6/96 Arizona IM240
Measured full IM240 emissions
Estimated full IM240 emissions, LBNL
Estimated full IM240 emissions, McClintock
Estimated full IM240 emissions, RFF
Estimated full IM240 emissions, EPA*
Cumulative Fraction of Vehicles
1
0.1
0.01
0.001
0.40
0.70
1.72
0.81
Ratio of fleet estimate to measured
0.2% are falsely fast-passed
0
5
10
15
20
25
30
CO (gpm)


NOx Distribution for Fast-Passed Vehicles
993 MY91+ cars passing start-up FP cutpoint, 1/96-6/96 Arizona IM240
Measured full IM240 emissions
Estimated full IM240 emissions, LBNL
Estimated full IM240 emissions, McClintock
Estimated full IM240 emissions, RFF
Estimated full IM240 emissions, EPA*
Cumulative Fraction of Vehicles
1
0.1
0.01
0.001
0.95
None are falsely fast-passed
0.51
0.24
1.01
Ratio of fleet estimate to measured
0.0
0.5
1.0
1.5
2.0
2.5
3.0
NOx (gpm)

Two Methods Applied to Wisconsin Data

In order to determine the effect of using a different adjustment methodology on fleet average emissions, we applied the LBNL, PM, and EPA methods to an independent set of data from the Wisconsin IM240 program.[11] We also used the PM method based on a random sample of full tests conducted in Wisconsin, using data supplied by Peter McClintock. Table 2 shows the average emissions for the MY82 to MY94 passenger car fleet predicted by each method, as well as the ratio of the prediction under each method to the prediction under the PM method derived from Wisconsin data. The source of the data used for each method is listed in parentheses in Table 2. We only applied the data to vehicles for which we could identify their type of fuel delivery system, as the EPA method relies on this information. By restricting the analysis to these vehicles, we ensure that each method is applied to the same vehicles.

The LBNL method consistently predicts lower fleet emissions than the PM (Wisconsin) method, particularly for cars passed after only 30 seconds of testing. On the other hand, the EPA method predicts slightly higher fleet emissions than the PM (Wisconsin) method, especially for HC and NOx. The PM method based on Colorado data predicts the same fleet HC emissions as the PM (Wisconsin) method, but predicts higher CO emissions and lower NOx emissions. This type of analysis only tells us the relative effect of each prediction method on fleet emissions; we cannot say which method is more accurately predicting full test emissions.

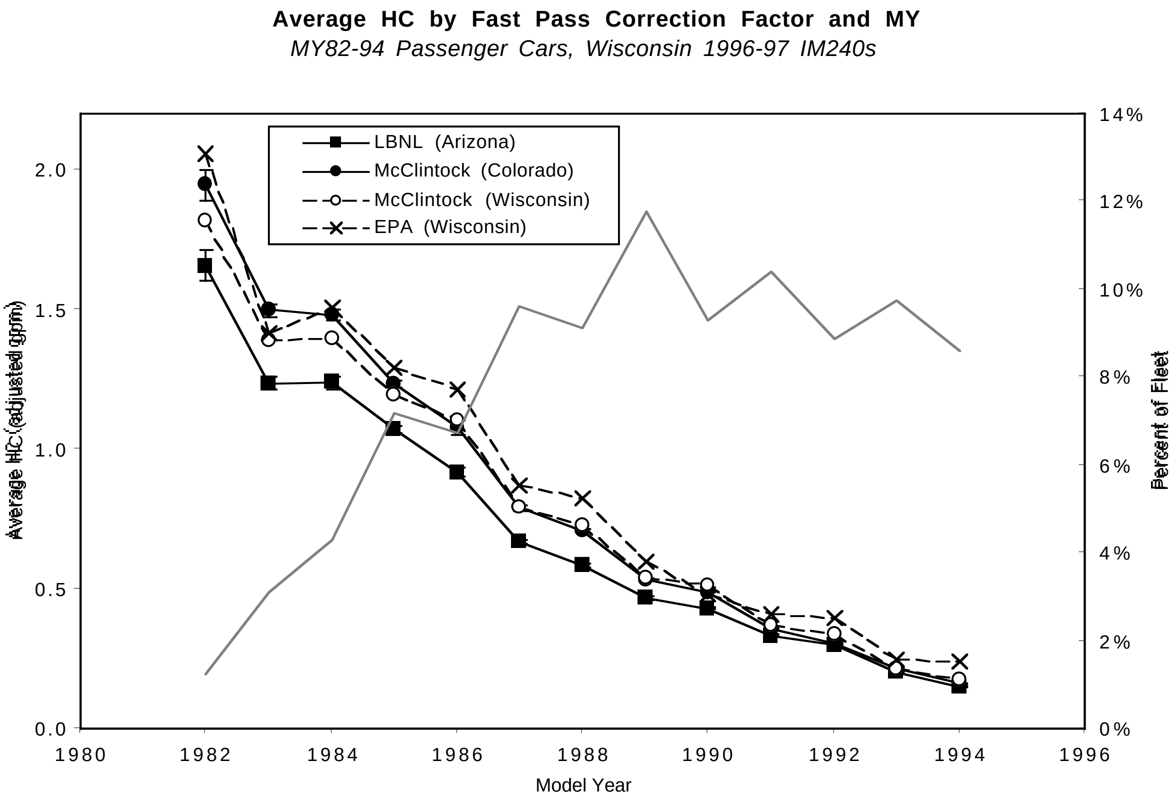
Table 2. Comparison of Different Methods on Wisconsin Data

	Average Predicted Emissions, gpm			**Ratio of Prediction to PM (Wisconsin) Prediction**		
	HC	CO	NOx	HC	CO	NOx
All tests						
LBNL (Arizona)	0.56	6.64	1.08	0.87	0.79	0.82
PM (Colorado)	0.64	9.94	1.15	**1.00**	1.18	0.87
PM (Wisconsin)	0.64	8.45	1.32	1.00	1.00	1.00
EPA (Wisconsin)	0.70	9.13	1.46	1.10	**1.08**	**1.11**
Cars passed after only 30 seconds of testing						
LBNL (Arizona)	0.23	2.26	0.71	0.62	0.45	0.68
PM (Colorado)	0.37	6.84	0.86	**1.00**	1.36	0.82
PM (Wisconsin)	0.37	5.02	1.04	1.00	1.00	1.00
EPA (Wisconsin)	0.43	5.22	1.18	1.15	**1.04**	**1.13**

The next three figures compare the average adjusted emissions for all MY82 to MY94 passenger cars by model year, under each prediction method. The HC figure shows the percent distribution of cars by model year, as a gray line. Both of the methods based on Wisconsin data (the PM and EPA methods) result in higher emissions from even-year vehicles; this is particularly evident for NOx under the EPA method. These peaks are likely due to the sample of vehicles given the full test in Wisconsin, which were used to develop the adjustment methods. Most of this testing was conducted in 1996; therefore, most of these vehicles were from odd model years. McClintock's

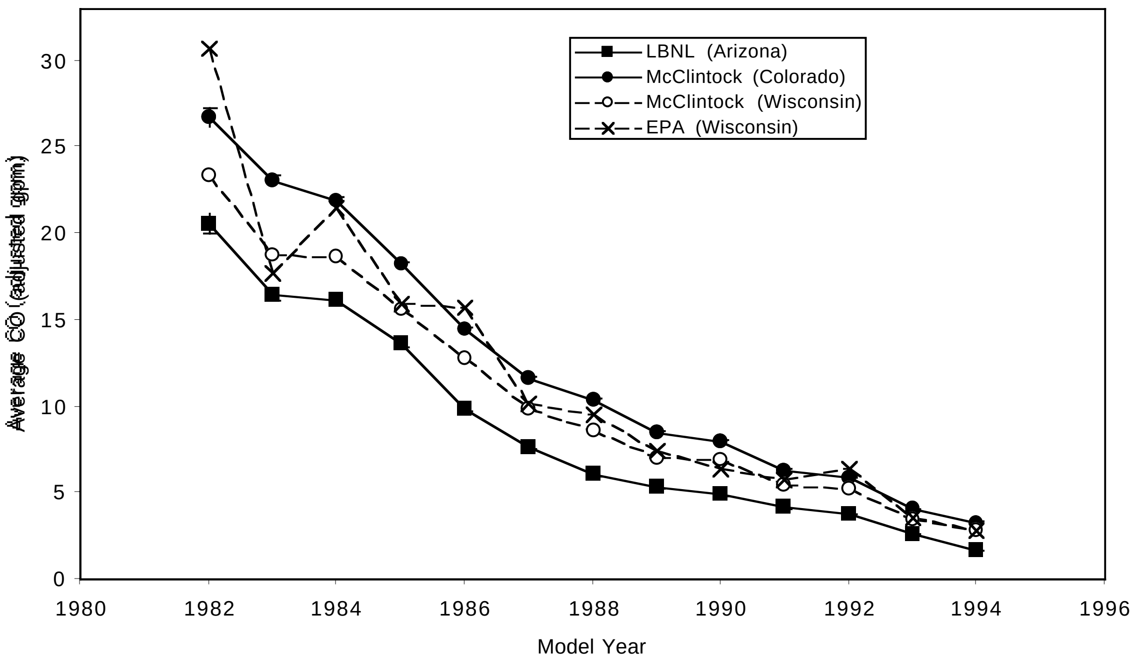
11. Like Colorado, Wisconsin's IM240 program does not allow vehicles to fast fail; all vehicles with high emissions are given a full IM240.

method results in smaller peaks because he grouped several model years together before calculating his adjustment factors.



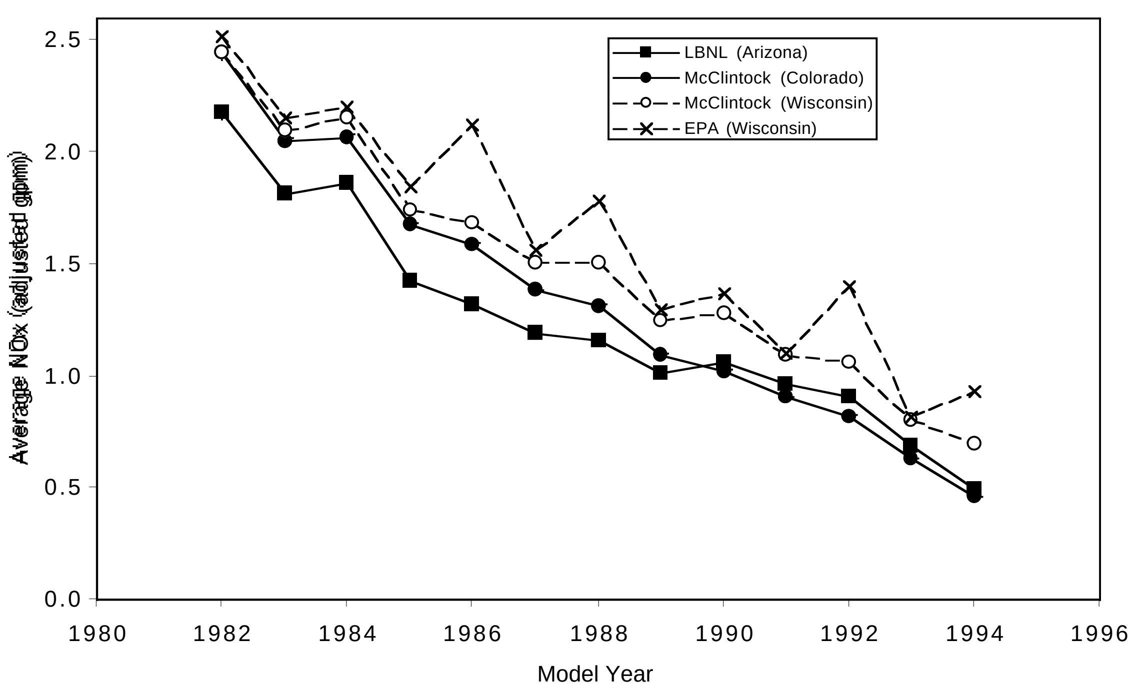
Average CO by Fast Pass Correction Factor and MY

MY82-94 Passenger Cars, Wisconsin 1996-97 IM240s



Average NOx by Fast Pass Correction Factor and MY

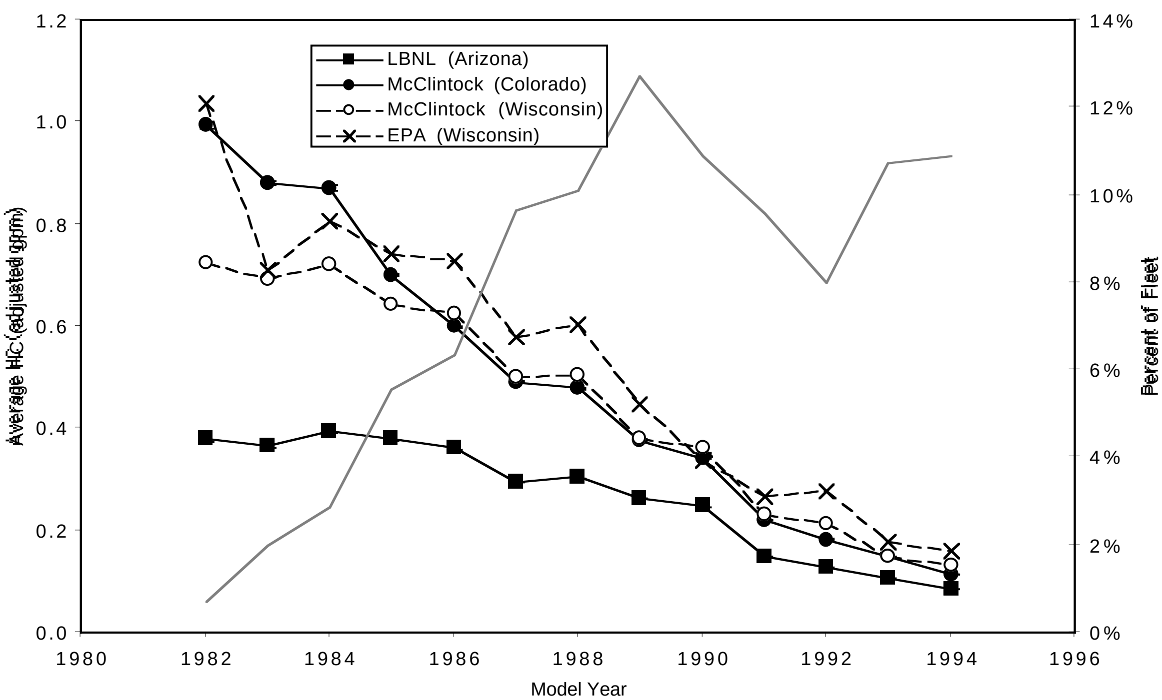
MY82-94 Passenger Cars, Wisconsin 1996-97 IM240s



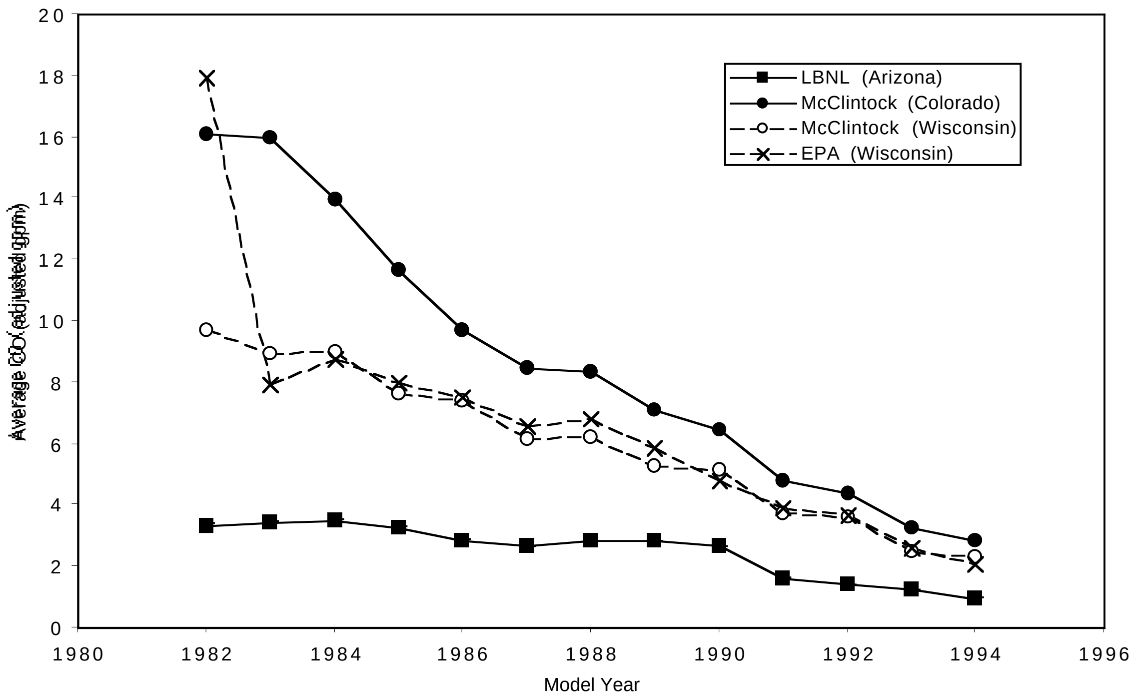
The next three figures compare the average emissions by model year for vehicles that are fast-passed after only 30 seconds of testing. The accuracy of an adjustment method after only 30 seconds of testing greatly affects the overall accuracy of the method, since most vehicles are passed at this time. In this sample nearly 70% of all cars were passed after only 30 seconds. Here we see much larger discrepancies between the LBNL method and the PM (Wisconsin) method, especially for older cars. Again, the HC figure shows the percent distribution of cars by model year, as a gray line.

Average HC by Fast Pass Correction Factor and Model Year

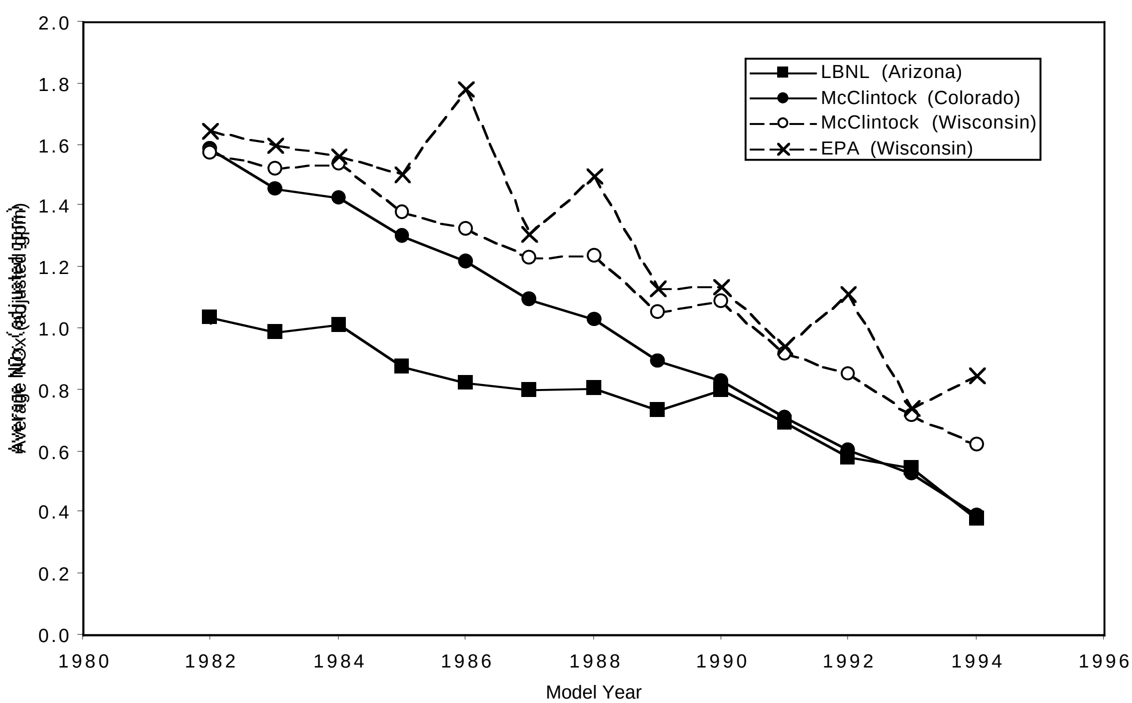
MY82-94 Passenger Cars Passed at Second 30, Wisconsin 1996-97 IM240s



Average CO by Fast Pass Correction Factor and Model Year
MY82-94 Passenger Cars Passed at Second 30, Wisconsin 1996-97 IM240s

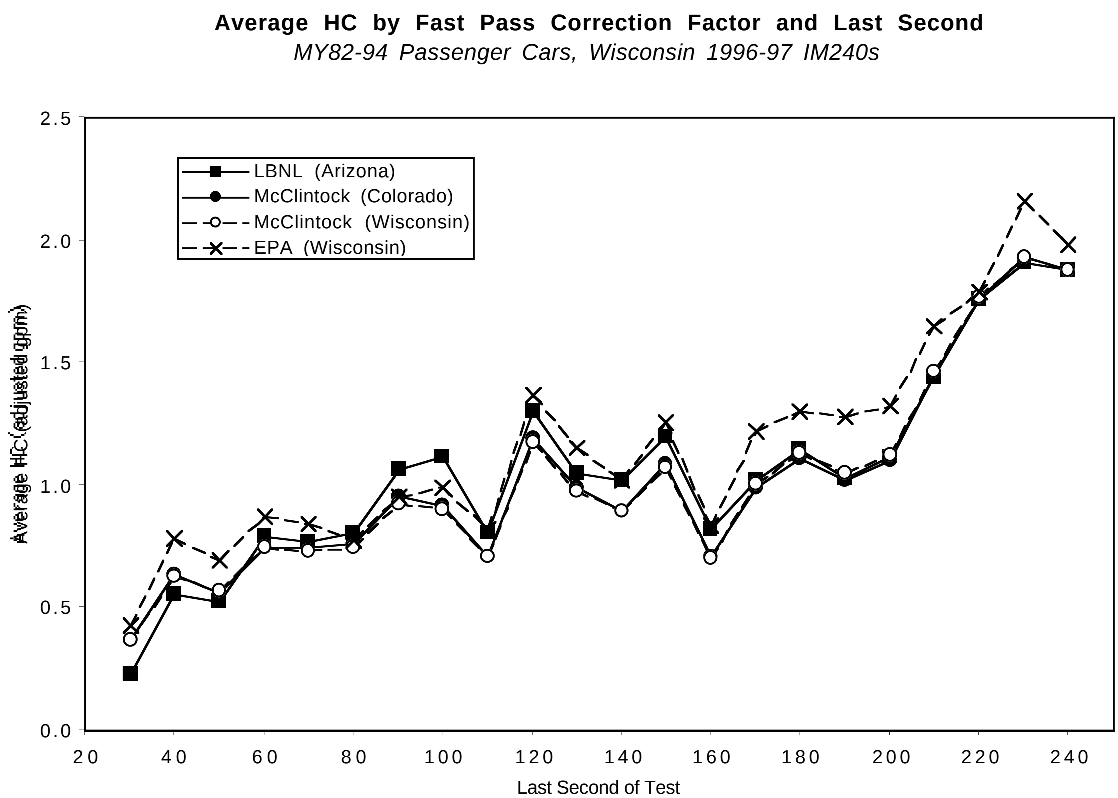


Average NOx by Fast Pass Correction Factor and Model Year
MY82-94 Passenger Cars Passed at Second 30, Wisconsin 1996-97 IM240s

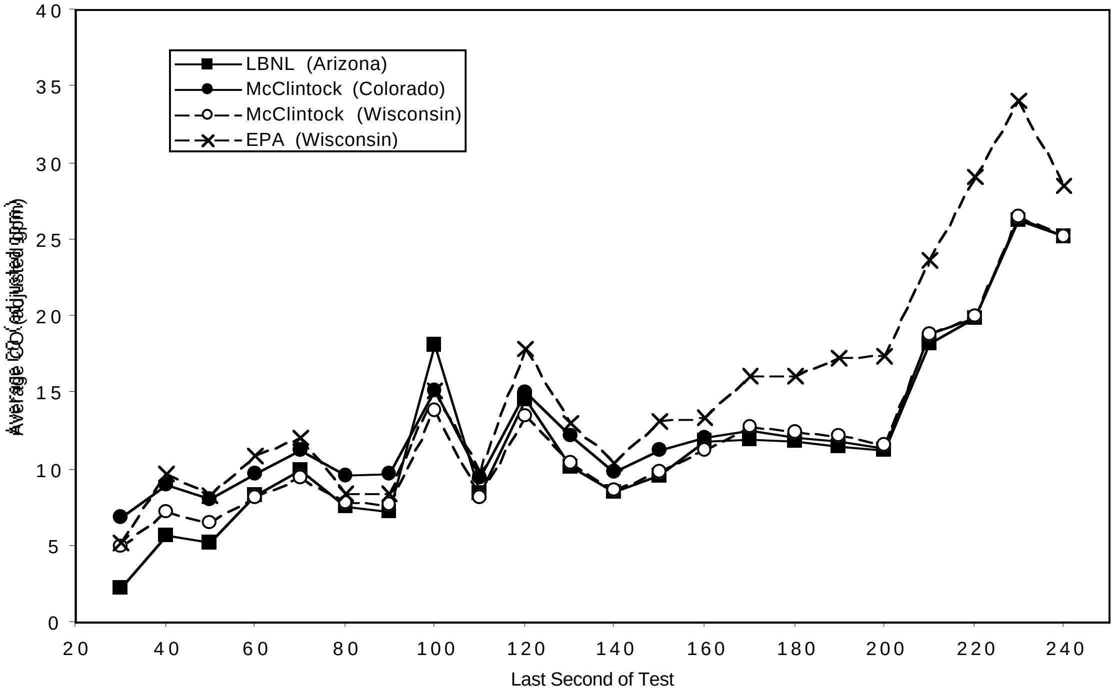


The next three figures show average emissions under each prediction method by the last second of the test. Average emissions at each 10-second point only are shown to reduce the complexity of the figure. Each method predicts relatively similar emissions to vehicles that are driven over different portions of the IM240 cycle; the shape of the curves by second of the test are quite similar using each prediction method. Nearly 70% of the cars are passed after only 30 seconds of testing; another 11% are given the full test. The test durations of the remaining 19% of the fleet are fairly evenly distributed over the other 209 seconds of the test.

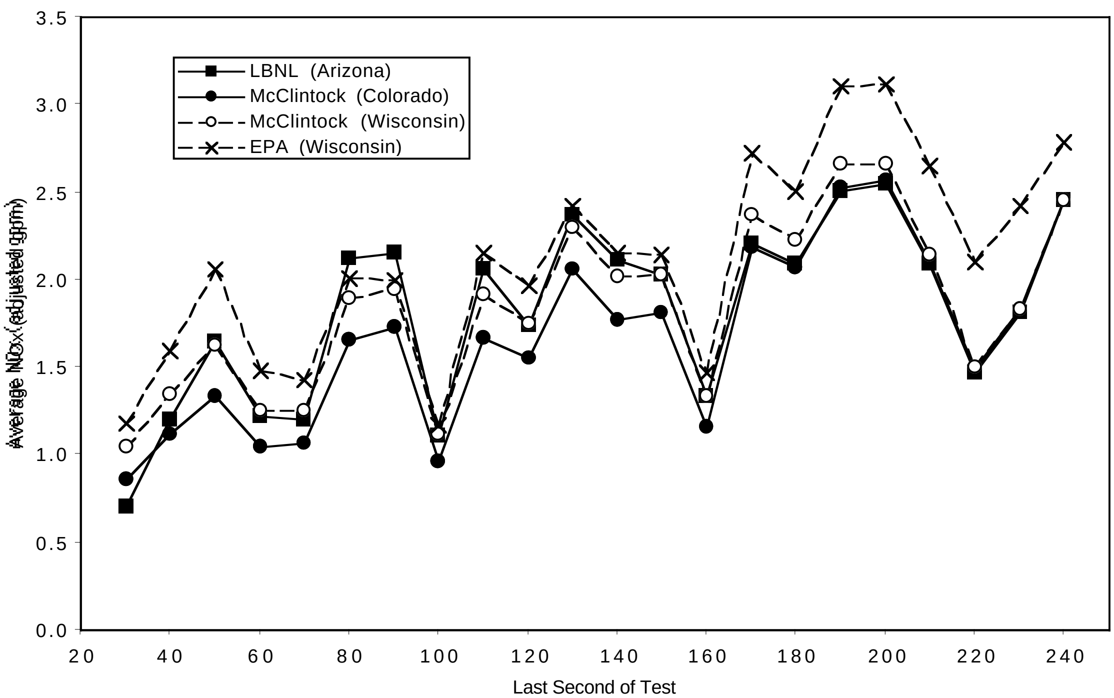
Note that all but the EPA method converge the further into the test cars are driven; the emissions at second 240 for all but the EPA method are identical. (Since the EPA method should not be applied to cars given the full IM240 test, in the preceding tables and figures the measured values for full IM240s were substituted for the values "predicted" by the EPA method.) The EPA method results in much higher emissions for vehicles driven further into the test than the PM (Wisconsin) method, particularly for CO and NOx. However, as mentioned above, relatively few cars are fast-passed this far into the test.



Average CO by Fast Pass Correction Factor and Last Second
MY82-94 Passenger Cars, Wisconsin 1996-97 IM240s



Average NOx by Fast Pass Correction Factor and Last Second
MY82-94 Passenger Cars, Wisconsin 1996-97 IM240s



Evaluation of LBNL Method

Finally, we compare the distribution of emissions from the random sample of vehicles given the full IM240 test in Arizona in 1996, with the adjusted emissions of the vehicles that were not given the full IM240 (i.e. those that were either fast-passed or fast-failed). The first figure compares the model year distribution of the cars in each sample, and indicates that the random sample appears to be quite representative of the entire population of vehicles tested under the Arizona I/M program.

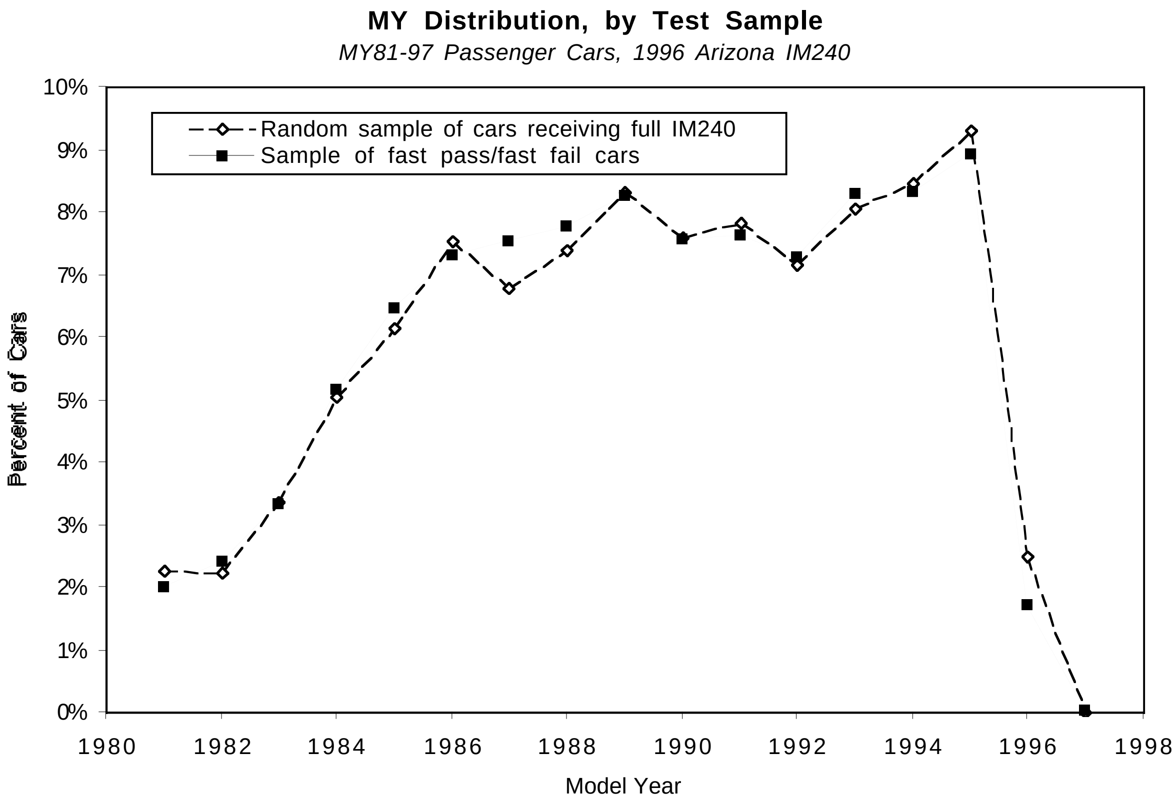


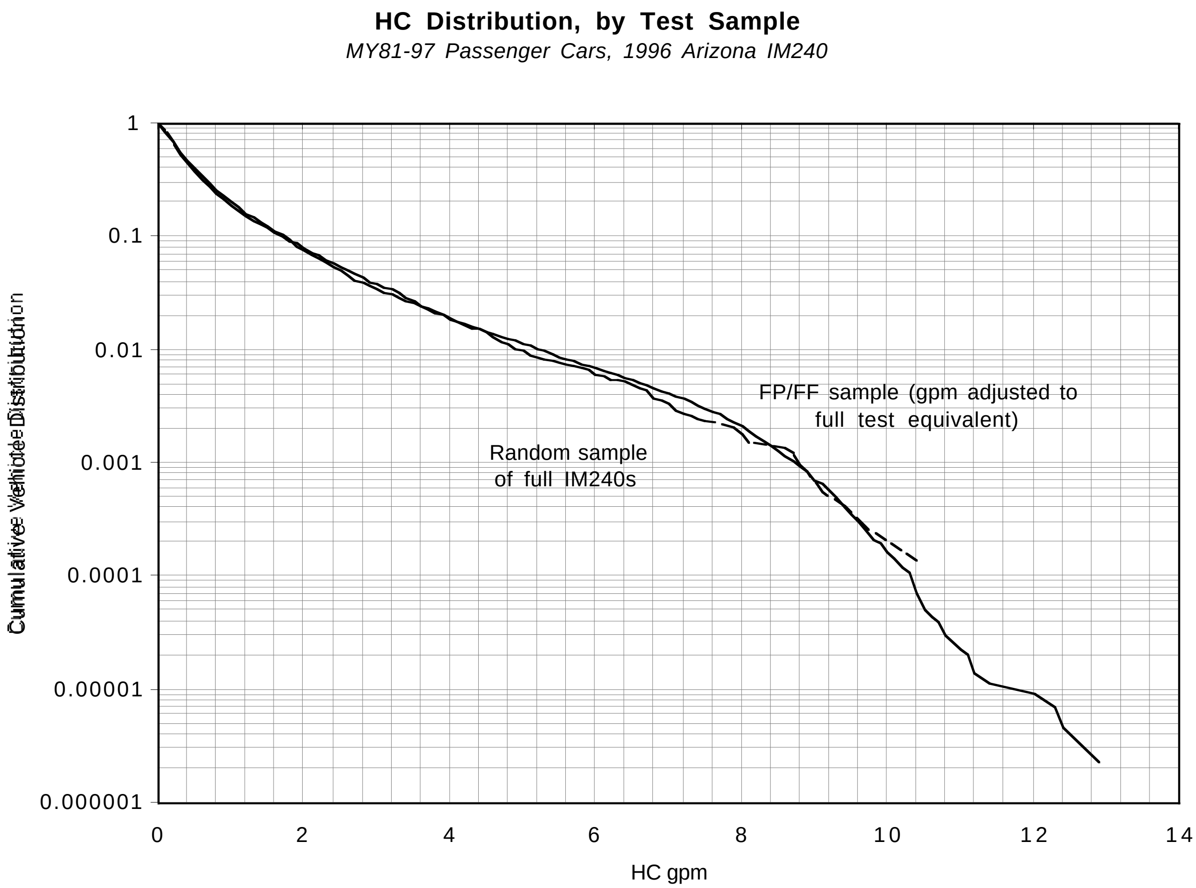
Table 3 compares the measured full test emissions, from the sample of vehicles given the full IM240, with the predicted full test emissions, from the vehicles fast-passing or fast-failing the Arizona IM240. The table indicates that the predicted emissions from the fast-pass/fast-fail vehicles are very similar to those from the random sample of vehicles.

Table 3. Comparison of Measured and Predicted Full Test Emissions, Arizona Random Sample and Fast-Pass/Fast-Fail Tests

	Average emissions (gpm)			Ratio of FP/FF to full test		
	HC	CO	NOx	HC	CO	NOx
Random Sample (n=7,209)	0.64	10.3	1.23	1.00	1.00	1.00
Fast Pass/Fast Fail (n=436,160)	0.66	9.5	1.22	1.02	0.93	0.99

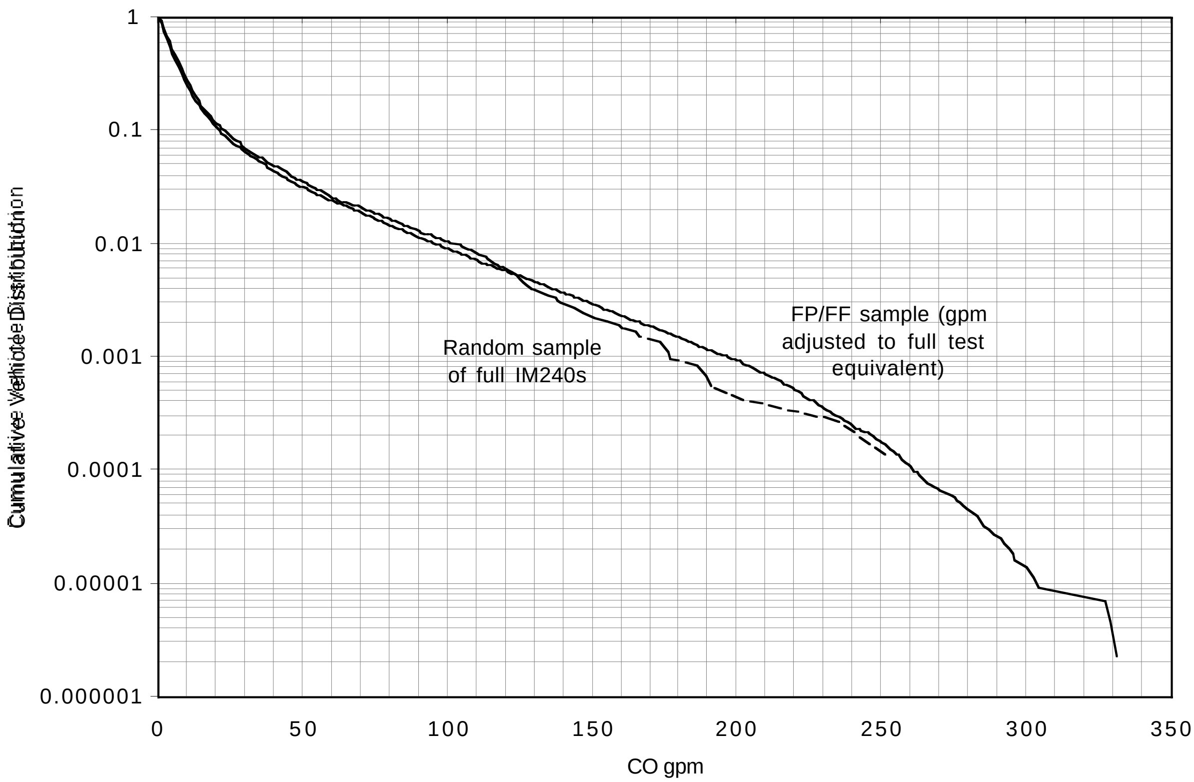
The next three figures show the emissions distributions of each pollutant by test sample. The figures indicate that the emissions distributions from both the random sample of full tests (dashed line) and the adjusted emissions from the FP/FF tests (solid line) are quite similar.

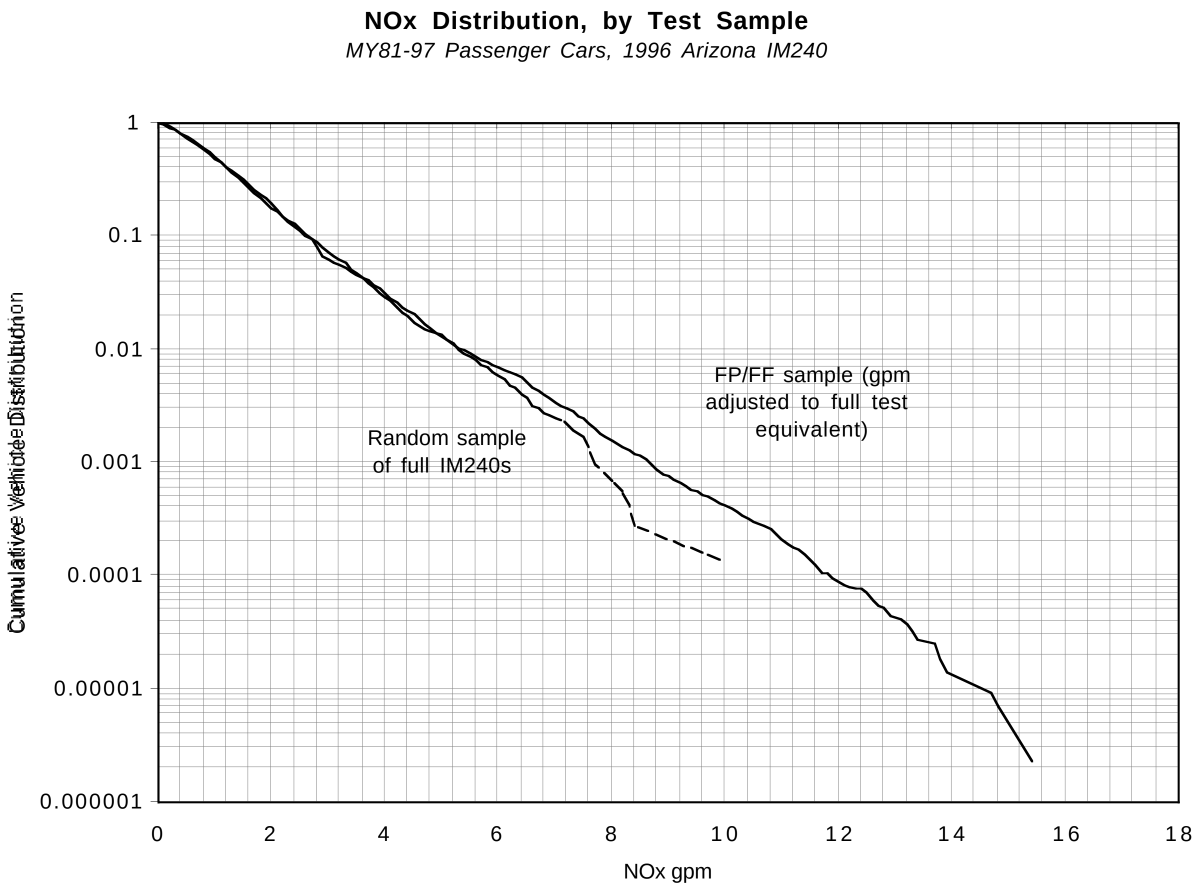
This similarity contradicts evidence presented earlier that the LBNL method underestimates the emissions of the majority of cars; that is, low emitting cars that pass after only 30 seconds of testing. We have not yet determined possible explanations for this discrepancy.



CO Distribution, by Test Sample

MY81-97 Passenger Cars, 1996 Arizona IM240





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